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Impacts of Technology on U.S. Cropland and Rangeland Productivity

Volume II—Background Papers

Part E

Paper No.

20. The Impacts of Grazing and Rangeland Management Technology Upon Wildlife
21. A Review of Current Water Erosion Control Technologies, Including Potential Changes To Enhance Their Effectiveness
22. Technology Issues in Developing Sustained Agricultural Productivity on Virgin and Abandoned Lands in the United States
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26. Data Availability for the Assessment of Technologies and Public Policies Relating to Agricultural Productivity

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Preface

This volume contains papers written for OTA to assist in preparation of the report *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

Background Paper No. 20

THE IMPACTS OF GRAZING AND RANGELAND MANAGEMENT TECHNOLOGY UPON WILDLIFE

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Abstract

Originally, the nation could claim a vast and diverse assortment of highly productive grazing lands. Before European settlement, these lands supported immense herds of native herbivores and a rich diversity of predators. Rangeland environments were balanced and stable.

Settlement exposed pristine rangelands and wildlife to all the vagaries of civilization and initiated declines in these resources that continue even today. Early and unregulated growth of the open-range livestock industry quickly saturated western public ranges and brought about serious deterioration. By the time federal controls were instituted, much of the damage had already been done.

Today, with a large portion of public rangelands in poor condition, livestock grazing continues to exert harmful effects upon all types of wildlife, fisheries, stream-side environments, vegetation composition, soils, water quality, and other range resources.

The nation's growth and demand for meat have led to a determined effort to restore and increase the productivity of public grazing lands. Congress and management agencies have rejected significant reductions of grazing on public lands, and have elected to spend vast sums on intensive management and range improvements, including massive seedings of exotic grasses, fencing, novel grazing systems, and other technologies.

Increasing demands by non-consumptive users, wildlife interests, and numerous others are generating conflicts with traditional dominant uses, such as livestock grazing. Public subsidies of the livestock industry, national dietary considerations, and changing public perceptions demand drastic revisions in the traditional policies for managing rangelands.

Historical Considerations

Original vegetation.

Before European settlement of North America, the major factors influencing ecosystems were climatic conditions, fires, and the activities of wild herbivores (1). Deciduous forests covered most of the eastern United States. Abundant precipitation discouraged extensive fires in many regions, but fires were prevalent in drier areas, especially in the Southeast. These fires were started by lightning and Indians (2). Bison (*Bison bison*), which grazed as far east as Tennessee, Kentucky, Indiana, and Ohio, helped to discourage the spread of deciduous forests and to maintain grassland communities (3). Average annual precipitation was probably similar to today's—28 to 60 inches.

Along the western edge of the deciduous forests, where true prairie covered the eastern Great Plains, annual precipitation averaged only 30 to 40 inches. Fires were an important factor on the prairie and apparently served to resist the invasion of deciduous trees (4). Conditions became drier west of the true prairie, and in the western Great Plains, precipitation averaged 14 inches, and short varieties of drought-resistant grasses dominated.

Climatic conditions in the Rocky Mountains are probably not much different than in pre-Columbian times. Today, annual precipitation varies from about 50 inches in northern Idaho to about 18 inches in southern portions of the range. The prevailing vegetation was coniferous forest, with alpine conditions at higher elevations. Lightning fires were prevalent, especially at lower elevations.

Between the Rocky Mountains and the Sierra Nevada and Cascade ranges lies a vast region of internal drainage—the Great Basin. Today, precipitation here is scant (6 to 18.5 inches). Shrubs were dominant on some sites, but interspersed with extensive stands of native bunchgrasses. Fires were a major factor in determining vegetation type. Shinn (5) reviewed the diaries of early travelers in the region and found numerous references to fires, mostly set by Indians. Lightning fires were also important, especially in late summer.

South of the Great Basin, in the most arid section of the nation, vegetation reflects meager and irregular rainfall—3.5 to 13 inches a year (2). Here, the original vegetation was dominated by widely scattered shrubs. Although a few grasses were present, these were minor in most communities, even though desert grasslands covered portions of southeastern Arizona, southwestern New Mexico, and southwestern Texas (6).

In most places along the Pacific Coast, 50 to 100 inches of precipitation favored western hemlock and western red cedar (2). Where precipitation was less, as along the California coast and southward, chaparral was dominant, primarily in response to a long dry season (2). Fires were common, occurring every 2 to 10 years in southern areas (7) and 20 to 25 years in northern chaparral (8).

Although short-term disturbances resulted from local climatic deviations, fires, and the grazing of large animals, pre-Columbian vegetation tended to be stable and in harmony with prevailing conditions.

Original rangeland biomes.

Pristine conditions on many western rangelands are unknown, because they were drastically altered before the original plant composition could be fully documented. The California grasslands are an example. However, in most areas remnants of the native flora are preserved in protected places (e.g., cemeteries), and a reasonable assessment of the species composition of original communities is possible.

Stoddart et al. (9) defined rangelands as "those areas of the world, which by reason of physical limitations—low and erratic precipitation, rough topography, poor drainage, or cold temperatures—are unsuited to cultivation and which are a source of wood products, water and wildlife."

Today, most suitable farmland has been plowed, especially in the Great Plains, where the tall-grass or true prairie has virtually disappeared. In a pristine state, the flora of the true prairie was a combination of grasses and forbs (i.e., herbaceous flowering plants). The most important grass on uplands was little bluestem (Andropogon scoparius), while big bluestem (A. gerardi) was dominant in lowlands. These grasses made up 72% of the vegetation. Important associated species were porcupine grass (Stipa spartea) and prairie dropseed (Sporobolus heterolepis) on uplands and cordgrass (Spartina pectinata) on bottomlands (9). Although grasses dominated, forbs were important, and a high percentage of nitrogen-fixing legumes accounted, in part, for the high productivity of the true prairie (10).

West of the true prairie was the mixed-grass prairie. Here western wheatgrass (Agropyron smithii), side-oats grama (Bouteloua curtipendula), needlegrasses (Stipa spp.), lovegrasses (Aristida spp.), and others grew in the lowlands, but short-grasses were on uplands. During periods of favorable precipitation, the lowland grasses invaded favorable sites as far west as the Rocky Mountains; in unfavorable years, they dominated poorer sites on the tall-grass prairie (9).

From the 100th meridian west to the Rocky Mountains was the short-grass prairie. This prairie extended into southern New Mexico and central Texas and merged into the desert-grasslands. Large isolated tracts were also in northern Arizona. In the north, short grasses extended into Canada. Blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) were dominant species, occurring with various other grasses, forbs, and shrubs (9).

In parts of the Southwest, desert grasslands occurred. In such places, the vegetation was highly variable—sometimes nearly a pure stand of grass and other times an open savannah with an overstory of desert shrubs. The most important grass was black grama (*Bouteloua eriopoda*). Another was bush muhly (*Muhlenbergia porteri*). Trees and shrubs associated with grasses included mesquite (*Prosopis juliflora*), creosote bush (*Larrea divaricata*), yucca (*Yucca spp.*), cacti (*Opuntia spp.*), acacia (*Acacia spp.*), and oaks (*Quercus spp.*). Junipers (*Juniperus spp.*) grew on rocky slopes and washes (9).

From the Okanogan highlands of Washington, south into southern Oregon and Idaho, bunchgrasses predominated. Southward, this bunchgrass merged into the intermountain shrub region along an indistinct boundary. Dominant grasses were bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*). Needle and thread grass (*Stipa comata*), Sandberg's bluegrass (*Poa secunda*), and others were present. Great Basin wild rye (*Elymus cinereus*) was prevalent in bottoms and on clay soils (9).

South of the bunchgrass region, shrubs, such as big sagebrush (*Artemisia tridentata*) and shadscale (*Atriplex confertifolia*) were dominants. According to early writings about the northern Great Basin, the pristine vegetation was often dominated by dense stands of shrubs (11). Grass stands were mostly confined to valleys, moist canyons, and mountain slopes, although large parts of eastern Oregon, near the Cascade Range, may have supported grasslands. The grasses were primarily the same species found in the bunchgrass region to the north. Soils were important in determining shrub distribution, e.g., shadscale prevailed in soils with high alkalinity—sagebrush was found on less alkaline soils. Rabbitbrush (*Chrysothamnus spp.*) and greasewood

(Sarcobatus vermiculatus) were also important.

The California grasslands have been so altered that the nature of the original vegetation is obscured. The Coast Range and Sierra Nevada foothills were predominantly grasslands, and Stoddart et al. (9) believed nodding needlegrass (Stipa cernua) to have been dominant. Burcham (12), however, viewed purple needlegrass (S. pulcha) as the dominant. Identifying other native grasses and associates is a hopeless task.

Muir (13) referred to the abundance of forbs in the California Central Valley as follows: "one sweet bee garden throughout its entire length, north and south, and all the way across from the Sierra to the ocean." He went on to state, "The great central plain of California during the months of March, April, and May, was one continuous bed of honey-bloom, so marvelously rich that, in walking from one end of it to the other, a distance of more than 400 miles, your foot would press about a hundred flowers at every step. Along the rivers there is a strip of bottom-land countersunk beneath the general level, and wider toward the foothills, where magnificent oaks, from three to eight feet in diameter, cast grateful masses of shade over the open, prairie-like level."

In the arid Southwest, creosote bush was the dominant plant, much as today. These shrubs were usually widely scattered, with numerous cacti interspersed among them. Bottomlands and flats supported stands of mesquite. Grasses were probably never abundant, but bush muhly and big galleta (Hilaria mutica) were present in some localities (9).

Coniferous forests formed the dominant vegetation in the Rocky Mountains. At lower elevations ponderosa pine (Pinus ponderosa) grew with an understory of scattered shrubs—Gambel's oak (Quercus gambelii), snowberry (Symphoricarpos spp.), and others. Dominant grasses varied with latitude. In the southern ponderosa pine belt, grasses included Arizona fescue (Festuca arizonica), hairy dropseed (Blepharoneuron tricholepis), and others. In the central Rocky Mountains, dominant grasses were hairy dropseed, slender wheatgrass (Agropyron trachycaulum), and species of oatgrasses. In the far north, bluebunch wheatgrass, Canby's bluegrass (Poa canbyi), pinegrass (Calamagrostis rubescens), and sedges (Carex spp.) grew at lower elevations (9).

Historically, fires have been ecologically important in ponderosa pine forests. Fires thinned the stands, eliminated young trees, and kept the forest open and park-like. The frequency of fires has varied regionally. In Arizona and New Mexico, fires burned at 4.8 to 11.9 year intervals, in Washington at 6 to 47 year intervals, and in Colorado at 12 to 25 year intervals (14). Most fires are attributed to lightning.

Above the ponderosa pine are zones dominated by Douglas fir (Pseudotsuga menziesii), lodgepole pine (Pinus contorta), and aspen (Populus tremuloides). Pinegrass is abundant in these zones. At higher elevations, Engelmann spruce (Picea engelmannii), blue spruce (P. pungens), and sub-alpine fir (Abies lasiocarpa) occur. Here a dominant grass was probably Thurber's fescue (Festuca thurberi) (9).

Above timberline the vegetation had the appearance of alpine meadows, with low vegetation of succulent forbs, and several species of grasses and sedges (2).

Pristine wildlife populations.

Estimates of wildlife numbers present in pre-Columbian times amount to little more than educated guesses. Seton (15) estimated populations of several large herbivores, and his estimates continue to be used today. Others have recently revised some of his estimates.

According to Seton, pre-Columbian bison numbered 60 million, but McHugh

(16) would accept only 30 million. Many of these bison lived in Canada, and most in the United States lived east of the 100th meridian (17). Two North American races are recognized—the plains bison (B. b. bison) and wood bison (B. b. athabascae). Historically, the distribution of the two types overlapped along the east slope of the Rocky Mountains (18). The plains bison ranged into southern Texas, eastward to northern Georgia, western Virginia, Pennsylvania, and southwestern New York, and northward to central Saskatchewan. The wood bison ranged from northern Alaska, south to northwestern New Mexico, and west into northeastern Nevada, eastern Oregon, and eastern British Columbia (19). Wagner (17) estimated that 5 to 10 million bison inhabited the plains of Montana, Wyoming, and Colorado, and the intermountain valleys and mountains to the west.

The plains bison congregated in immense herds on the Great Plains. One herd described along the Arkansas River in May 1871 was estimated at 12 million (3). The larger, darker, hardier, and more fleet and wary wood bison lived in smaller herds (18). Shinn (5) presented evidence attesting to the scarcity of bison in the intermountain region: (1) Many native tribes west of the continental divide journeyed across the Rockies to obtain bison meat and hides; (2) In 1820, the native peoples of the Lewis River Valley in Idaho reported large herds to be present at the time, but noted that such was an unusual event; (3) A Nez Perce folk tale proclaimed that coyote, the cultural hero of the tribe, attempted to bring bison across the eastern mountains but succeeded only in bringing them as far as the Bitterroot Range, Montana; and (4) Apparently large herds of grazers did not influence the evolution of the native vegetation of the northern Great Basin.

Bison were mainly grazers, and large herds required huge tracts of grasslands. Once a local area had been grazed, the herd moved to other feeding sites (18).

Pronghorn (Antilocapra americana) numbers were probably similar to those of bison, however their distribution was different—about 15 million in the Great Plains, 15 million in California, and 15 million in the arid West and Mexico. Generally, the species inhabited drier portions of the grasslands (2). According to archaeological investigations, pronghorns were the most important source of meat for desert-inhabiting Indians along the Nevada-Utah border (17).

Pronghorns prefer forbs and shrubs, but eat some grasses. The composition of vegetation in the sagebrush-grassland community on preferred pronghorn ranges was 40-60% grasses, 10-30% forbs, and 5-20% browse. Historically, pronghorns grazed with bison, elk (Cervus elaphus), mule deer (Odocoileus hemionus), and bighorn sheep (Ovis canadensis) without intolerance or competition (18).

Pronghorns were probably the most abundant large herbivore in the interior West in pre-settlement times. On the Great Plains, they fed on shrubs and forbs of disturbed sites after bison grazed the grasses (17).

At one time, the American elk was the most widely distributed member of the deer family in North America. They ranged from coast to coast, and from Mexico to northern Alberta, with the exception of the southern coastal plains and the Great Basin (18). Seton's (15) estimate of pre-Columbian elk in North America was 10 million. Wagner (17) estimated 2 million in the western one-third of the United States.

On a frequency basis, grasses and sedges represent 65.6% of the elk diet, woody species 28.6%, and forbs 7.6% (18).

Bighorn sheep were once widely distributed, inhabiting lowlands as well as mountains. Seton (15) estimated an original population of 1.5 to 2 million bighorns in North America, but Wagner (17) thought this number conservative. Originally, bighorns were distributed from British Columbia east to North and South Dakota and Nebraska, south through western Texas and northern Mexico, and west to the Sierra Nevada and Cascade mountains in California, Oregon, and Washington (18). Few animals were so well adapted to extremes in elevation and temperature. The range extended from the snowfields of the Canadian Rockies to the edge of palm tree stands in Baja California, and from high mountains in Colorado to the floor of Death Valley (18). Grasses, sedges, forbs, and browse (shrubs) are major foods.

Mule deer were found throughout the West from Minnesota, North and South Dakota, Nebraska, Oklahoma, and Texas west to the Pacific Coast (18). Deer, unlike other species, are more abundant today than in pre-Columbian times, and Wagner (17) believes Seton's (15) estimate of 13 million deer to be high.

Mule deer are "intermediate feeders"—adapted to a wide range of foods. Browse and forbs are staples in the diet, but grasses are also consumed. White-tailed deer (Odocoileus virginianus) were once distributed through most of the United States. As with mule deer, white-tails may be more numerous today than in pre-Columbian times. Browse is the principal food—grasses are seldom eaten.

Vegetation and herbivores co-evolved (17). In pre-Columbian times, the 11 western states supported 20-30 million grazing animals, and range vegetation was apparently enhanced by the diverse grazers.

When large numbers of native herbivores existed, they supported a large and diverse assemblage of carnivores. The largest of these predators, the grizzly bear (Ursus americanus horribilis), ranged from the Arctic coast of Canada, south to southern Durango, Mexico. Although only a few lived in the

Great Basin, the species inhabited much of Washington, western Oregon, and California. The eastern limit of the original range is uncertain, but records exist for western Texas, Kansas, South Dakota, and North Dakota (20). Coronado saw many grizzly bears when he traveled through the buffalo plains of Texas and Kansas in 1540 (15). The grizzly bear and wolf (Canis lupus) were the only predators associated with the immense herds of bison. However, bear predation on bison was probably infrequent, and from some accounts, the bears were not always winners (18).

Wolves were widespread and abundant in pre-Columbian times, but coyotes (Canis latrans) occurred originally only in modest numbers. Coyotes scavenged scraps left by wolves and caught rodents. In Mexico, Leopold (21) found that coyotes were scarce or absent in mature forests where wolves still occurred, but common elsewhere.

Originally, beaver (Castor canadensis) inhabited all of wooded North America (22). Seton (15) made numerous estimates of beaver densities in pre-settlement America. As many as 50 or 60 per square mile were estimated in regions of high densities. In the West, beaver populations were present along all wooded streams and ranged southwards into northern Mexico (21).

Other wildlife in pre-Columbian times seems to have been present in numbers comparable to those of large herbivores. Grinnell, described the abundance of Sage Grouse (Centrocercus urophasianus) in western Wyoming: "In October 1886, when camped just below a high bluff on the border of Bates Hole, in Wyoming (south of Casper), I saw great numbers of these birds just after sunrise flying over my camp to a little spring which oozed out of the bluff 200 yards away. Looking up from the tent at the edge of the bluff above us, we could see projecting over it the heads of hundreds of birds, and as those standing there took flight, others stepped forward to occupy their places. The number of grouse which flew over the camp reminded me of the old-time flights of passenger pigeons that I used to see when a boy. Before long the narrow valley where the water was, was a moving mass of gray. I have no means whatever of estimating the numbers of birds which I saw, but there must have been thousands of them" (23).

History of livestock in the United States.

The first successful introduction of livestock into the New World probably dates back to the early 16th century when Cortez brought sheep and cattle into Mexico. Cattle and sheep reached New Mexico in the 16th and 17th centuries and California in the latter part of the 18th century (24). There were more than a million sheep at Spanish missions as early as 1825 (17). Spanish settlers had large numbers of domestic livestock in Arizona before immigrants arrived from the eastern United States in the late 1800's (25).

The livestock industry has had its most colorful history in the western United States on the arid grasslands and in sagebrush and shrub country west of the 100th meridian. It should not be assumed, however, that the western ranges support most of the nation's livestock. The area east of the 100th meridian supports far more beef and dairy cattle than the West, and only in numbers of sheep does the West excel (24).

While some livestock were spreading from the East in the early 1800's, the center of livestock abundance was in the Spanish domain of Texas. When Texas entered the Union, little change in land-ownership policy took place. The state retained ownership of its public lands and continued the Spanish practice of disposing of lands to foster livestock production. Without nearby markets, owners often butchered cattle for hides and tallow, but in the 1840's, trail herds of Texas cattle were being driven to Louisiana and later to Ohio. When gold was discovered in California, many Texas cattle were driven there. In 1860, the number of Texas cattle was estimated at 4.5 million. After the Civil War, trail drives developed between Texas and railroad heads in Kansas. Between 1865 and 1885, an estimated 5.5 million were driven north—some to markets and others to stock newly opened ranges.

Settlement of the central and northern plains was delayed because of Indians. But in the 1870's, bison herds upon which the Indians depended were virtually eliminated. Between 1872 and 1874, nearly 3.7 million bison were slaughtered in the central plains. The bison slaughter on the southern plains was completed by 1878. The "mopping up" of the northern herd began in 1880, and the last large herd (10,000 bison) along the Cannon Ball River (North Dakota) was eliminated in 1883. With the passing of the bison, the habitat of the plains Indians was altered and destroyed, creating new opportunity for farmers and ranchers (3).

The nucleus of the western sheep industry began in New Mexico in the 16th century. In the 17th and 18th centuries, sheep were taken to New Mexico, Texas, Arizona, and California. By 1850, sheep numbered 514,000 in the West, increasing to 20 million by 1890. In California, more than half a million sheep were brought into the state between 1852 and 1857. Later, large bands were moved from California into the Great Basin. The spread of sheep in the West generated bitter rivalry between sheep and cattle owners, and in some areas, the bitterness erupted into open warfare (24). Public rangelands were severely overstocked.

The winter of 1885-86 brought grief to the cattle industry in portions of the West. Losses were estimated to be 85% over wide areas (9). Many herds were nearly wiped out and others suffered severely. As a consequence, money that had flowed into the livestock boom became scarce.

Another disaster occurred in the Southwest in 1893. In 1870, Arizona had only 5,000 cattle, but by 1890 the state's ranges were stocked to capacity with more than a million head. In 1890, imminent disaster was averted by late spring rains. But the summer rains of 1891 were below normal, and in the early summer of 1892 stock began to die. When summer rains were again below normal, heavy losses occurred. By late spring of 1893, dead cattle were everywhere, and the estimated mortality reached 50-75% (25).

Adopting Spanish methods, the western livestock industry practiced open-range grazing and left stock on the range year round without supplemental feed. Virtually the entire western half of the nation was public land—claimed by the federal government. By gaining title to relatively small but strategic bottomlands and by controlling available watering sites, stockmen could be assured of exclusive use of vast acreages of nearby public range without costs. A dependence upon public rangelands has always been central to western livestock operations.

Government policy encouraged disposal of public lands, which were used to stimulate expansion and economic growth of the nation. Congressional acts, such as the Homestead Act of 1862, subsequent revisions, and other land disposal legislation, facilitated transfer of public lands into private ownership. By taking advantage of available opportunities, livestockmen obtained base properties, and in many instances, used devious means to patent large holdings of the public domain. With the invention of barbed wire in 1874, private lands began to be fenced, and some stockmen even fenced large tracts of public rangelands, in an illegal attempt to perpetuate exclusive use. In any event, it is crucial to note, that throughout the period of development of the western livestock industry, public lands were used without regulation, without cost, and generally without regard to any factor other than the livestockman's personal whim.

The establishment of the forest reserves in 1891 and the U. S. Forest Service (USFS) in 1905 marked the first efforts to stabilize and control grazing on public lands in the West. Initially, misunderstandings led to efforts to remove all grazing from forest lands, but ultimately local stockmen were permitted to graze livestock and were charged a nominal fee per head. Troubles arose when the Forest Service attempted to improve forest ranges by restricting livestock numbers or grazing season. Stockmen, accustomed to uncontrolled use of public lands, resented what they considered to be unwarranted government interference with grazing "rights".

Meanwhile, huge tracts of public domain lands remained unregulated and available for grazing without fee. These were lands shunned during the homesteading era—mostly unsuitable for crops, but useful for livestock grazing. In 1934 the Taylor Grazing Act was passed by Congress and brought the remaining public grazing lands under federal management and control. Eighty million acres were designated to be administered by the Grazing Service—a move generally opposed by stockmen. In 1946, the Grazing Service and General Land Office were combined to form the Bureau of Land Management (BLM). This agency became responsible for the management of more than 160 million acres of federal lands in western grazing districts (24).

Since the 1880's, western stockmen have grazed federal lands while opposing administrative regulation. Periodically, ranchers have attempted to bring pressure to bear on Congress to have public grazing lands transferred to private ownership. Stockmen's associations, which have exerted powerful influence in Washington, have sought in many sessions of Congress to remove grazing lands from the jurisdiction of the USFS and other government agencies and to turn such lands over to cattle and sheep interests (24).

Unstable market conditions, drought, and severe winters ended the unregulated expansion of the livestock industry in the late 1880's and 1890's. The expansion took place at great expense to the developing nation. Public costs were revealed in the first general survey of the western ranges by the Forest Service in the 1930's. The survey revealed that the carrying capacity of range vegetation had been diminished by one-half since the arrival of livestock. The original carrying capacity of the native vegetation—22.5 million Animal Unit Months (AUM's)—had been reduced to 10.8 million. Even at that time (1930) livestock representing 17.3 million AUM's were still grazing the public rangelands (24).

In the 11 western states, the number of sheep reached nearly 20 million by 1895, varied between 20 and 30 million for the next half century, then declined by two-thirds after 1945 (17).

Cattle numbers were highest in the West during the half century when sheep were also at a maximum. Total numbers of cattle dropped slightly in the 1950's, when sheep also declined. But during the past 20 years, cattle increased, and have approached the numbers present at the turn of the century. A growing share of these cattle has been fed hay, grain, and silage in feedlots and on farms for portions of the year. Feedlots and other operations have permitted a total increase in cattle in the West, without significantly increasing demands for public forage. The development of range management techniques has further relieved pressures upon public ranges. However, the average weight of cattle today is about 1,000 pounds, compared to 800 pounds in 1900, thus the use of AUM's to compare intensity of range use through time is subject to enormous error. Also range carrying capacity is lower today than it was 75 to 100 years ago, and vast parcels of rangelands have been diverted to farms, orchards, urban development, impoundments, highways, national and state parks, and industrial complexes (17).

Current Status

Present practices.

Excluding Alaska and Hawaii, the land area of the United States consists of 1,904 million acres. In 1959, 21% was in cropland, 27% farm pastures, 24% forest land, 17% grazing lands, and the remaining 11% in cities, highways, parks, barren desert, etc. The amount of available forest and rangeland has decreased in each decade, but recently the acreage has tended to stabilize. However, an estimated 1 million acres a year are being lost to paving, housing, cities, highways, industries, and airfields (26).

Rangelands have not fared well since European settlement. Much of the Great Plains is now in the grain belt, and only remnants of the tall grass and mixed prairies have escaped the plow. Overgrazing by domestic livestock has drastically altered the vegetation over most of the remaining western states. Nearly half of the total land area in the 11 western states is federally owned, and more than 75% of this land is grazed by livestock. Seventy percent of these grazed lands are producing less than 50% of their potential (27).

Of federal lands in the 11 western states, BLM administers about 174 million acres and the USFS 187 million acres. BLM lands, exclusive of Alaska, include more than 400 thousand acres of lakes and reservoirs, 19 thousand miles of fisheries streams, and 500 thousand acres of riparian lands and wetlands. On USFS lands there are 2.4 million acres of lakes and reservoirs, 84 thousand miles of fisheries streams, and 2.3 million acres of riparian lands and wetlands (28).

According to a Special Task Force Report on BLM lands issued in December 1974, more than 47 million acres of National Resource Lands considered usable by livestock were in either poor or worse condition. Excluding grasslands, only 13% of the desert, 14% of the woodland-brushland, and 24% of the coniferous forests were rated as good to excellent (29). Gallizioli (29) further reported that USFS lands were in almost as deplorable a state as BLM lands. Of the 21 million acres of grazed Forest Service lands in New Mexico and Arizona, 30% was classified as poor or very poor. The USFS has controlled forests since 1905. Because the Forest Service has more staff per unit of rangeland and more stringent regulations, the unacceptable condition of national forests is far less excusable than that of BLM lands.

The United States produced 122,896,000 cattle in 1977. Only 2,211,000 cattle were produced on BLM lands—60% of all federal lands—and these accounted for less than 1.8% of the nation's cattle production. Add those produced on USFS lands in 1975 (1,450,720), and the total cattle produced on public ranges amounts to only 3% of the national total (30).

The U. S. Fish and Wildlife Service (USFWS) is also involved with livestock grazing. At Malheur National Wildlife Refuge, in southeastern Oregon, about 48,000 AUM's are used during the winter months. Although use is down from the 129,000 AUM's allotted in the early 1970's, overgrazing is still evident. Seemingly, the overgrazing of lands set aside for the protection and production of wildlife violates the intent of the federal wildlife refuge system. Malheur Refuge is not an exception—many refuges in the West are immersed in grazing problems.

In general, at least in southeastern Oregon, many private lands seem to be better managed than most public lands. Many ranchers near Malheur Refuge graze cattle on refuge lands in the winter and move to BLM lands in summer. When the refuge manager was asked to justify cattle on the refuge in March, when trampling damaged wet soils, his reply was that the BLM would not accept them in March and the local ranchers did not want them on their private land at a time when cattle would damage meadows! Such reasoning and decision making is obviously not in the public interest.

Cattle tend to concentrate in riparian zones in response to lush grasses, water, and shade. This behavior has degraded or destroyed thousands of miles of streams and fish habitat. Collapsing banks, loss of riparian vegetation, silting of spawning beds, and widening and shallowing of streams are normal operating procedures throughout the West. A BLM report concerning Nevada stated that, "Stream riparian habitat where livestock grazing is occurring has been grazed out of existence."

Native grasses have been eliminated from vast portions of the West. Shrubs and exotic forbs and grasses currently dominate the vegetation, and only in a few regions have vegetation changes been properly documented.

Vegetation changes are recorded for the Cache Valley in Utah and Idaho. Explorers and early settlers found abundant grass and little sagebrush. But excessive livestock grazing has caused grasses to decrease and sagebrush to increase, and much of the original grassland has been plowed for farming. Some tracts that have not been plowed, irrigated, heavily grazed, or burned continue to support essentially the same vegetation described by early travelers. In those portions of the valley where livestock grazing has occurred, the dominant vegetation is now sagebrush (31). Other reports conclude that northern Utah and southern Idaho were essentially a grassland with little sagebrush. Uncontrolled grazing has reduced perennial, native grasses and allowed sagebrush to increase (31).

In the desert grasslands, pure stands of grass are now rare. Intense grazing by cattle has favored increased shrubs at the expense of grasses (9). The grasslands of California, because of fire and overgrazing, are completely and probably permanently dominated by exotic annual grasses (9).

Throughout the West, as native, perennial grasses disappeared or were reduced, exotic annual grasses took their place. Cheatgrass (Bromus tectorum) was first noted in the 1890's. The introduced species rapidly invaded sites where the native perennials had been disturbed or lost through cultivation, grazing, fire or construction (32). Today, cheatgrass is the most visible species over much of the western United States. It is especially common in Oregon and Washington, but occurs from Alberta south to Texas (33).

In 1974, estimates showed that since 1900, 30% of all sagebrush land in Colorado had been "treated" to remove sagebrush. Elsewhere in the West, it is conservatively estimated that 10% of the sagebrush rangelands has been altered (34). After sagebrush is killed, usually with an herbicide, most lands are planted with crested wheatgrass (Agropyron cristatum), a species of perennial bunchgrass introduced from Russia. Crested wheatgrass provides useful forage for livestock, especially in the spring, but large, pure stands have minimal value for wildlife. In Idaho, Reynolds and Trost (35) found such seedings to support fewer species of nesting birds and a lower density of birds, mammals, and reptiles than areas dominated by sagebrush. Four species of birds require sagebrush in their habitats, e.g., Sage Grouse, Sage Thrasher (Oreoscoptes montanus), Sage Sparrow (Amphispiza belli), and Brewer's Sparrow (Spizella breweri); and two other species of birds are nearly dependent upon sage (34).

The pinyon-juniper vegetative type is estimated to cover about 75 million acres of the United States. In most areas, juniper has been historically confined to rocky ridges and rimrocks where soils are poor and shallow, but today, juniper has spread and formed dense stands in other places. From the original habitat, junipers have invaded and continue to invade deeper soils previously occupied by grasslands and sagebrush-grass. In 1964, junipers covered about 21.5 million acres in Texas and had increased about 3.5 million acres in the preceding 15 years. Reasons given for juniper invasion onto deeper soils of the grass-sagebrush communities of the Great Basin include overgrazing, lack of periodic fires, effective seed dispersal, and climatic fluctuations (32).

In Oregon, Shinn (5) observed that young western juniper (Juniperus occidentalis) was highly susceptible to destruction by fire. Junipers seem to be eliminated from areas exposed to fire at least every 15 years (36). In Utah, Shinn (5) noted, "...herbaceous competition was seen to have prevented invasions of grassy hillsides by Utah juniper (J. osteosperma) prior to European settlement in 1862. Heavy grazing by cattle and sheep occurred after 1864, and soil moisture was severely reduced by erosion in 1884." Juniper populations expanded nearly 500% between 1864 and 1934.

Also in Utah, Blackburn and Tueller (37) reported that Utah juniper and pinyon pine (Pinus monophylla) had invaded black sagebrush (Artemisia nova) communities in 1923. By 1966 dense stands of pinyon pine and juniper were dominant. The change was attributed, in part, to overgrazing and fire suppression.

A stable ecosystem has a constant turnover of materials, with those lost being replaced from the atmosphere or soil (26). If this balance is upset, the ecosystem is degraded. Soil and vegetation determine rates of water infiltration and sedimentation on rangelands. Grazing reduces the infiltration of water into soils and increases erosion by impaction (38). In significant portions of the western United States—areas of heavy, prolonged grazing by too many livestock—a point of no return has been reached. Erosion and soil destruction are too far advanced to permit recovery within an acceptable period of time (26).

In Texas, infiltration rates on a grazed area were only one-half of those in a rotation pasture and exclosure. The grazed pasture also had greater sediment production than the other two areas (38). Once vegetation and litter have been removed, infiltration declines. Thereafter, precipitation fails to penetrate the soil and runs off, carrying soil particles into streams and resulting in siltation and reduced fish production.

Numerous references document a reduction in wildlife populations from overgrazing. Bighorn sheep and American elk are known to abandon areas where cattle have been introduced (29, 40). Livestock grazing on summer mule deer and winter pronghorn ranges leaves little winter food for these species. Cattle are predominantly "grazers" and deer "browsers", but on overgrazed rangeland, cattle will eat anything palatable, including types of shrubs normally used by deer (29).

Other wildlife populations are also influenced by overgrazing. Streams in northern Arizona inhabited by the threatened Arizona trout (Salmo apache) have been degraded by overgrazing. Trout populations in many western states have been markedly reduced by grazing (29).

Certain bird populations have suffered severely. The Masked Bobwhite (Colinus virginianus ridgwayi), which occupied the desert grasslands of Arizona, has been extirpated from most of its range within the state. Other upland game birds have suffered from the effects of livestock grazing, but to a lesser extent than the Masked Bobwhite.

Buttery and Shields (41) summarized the deleterious effects of livestock grazing on small bird populations. Also, some lizard populations have declined as a result of livestock grazing (42, 43), and Berry (44) reported adverse influences of livestock upon the desert tortoise (Gopherus agassizi) in the Southwest.

Effects of Grazing upon Ecosystems

Nature of domestic grazers.

The diets of domestic and feral livestock vary, resulting in abuse to specific plants and habitats but little damage to others. Thus, cattle are primarily grass eaters and may degrade lush stands of grasses in riparian zones, while upland grasses away from water go unused. But when the grass supply has been depleted, cattle will turn to various other plants—the order of preference being grasses, forbs, and finally shrubs. By volume, forb and shrub consumption are small in relation to grasses. Sheep, however, tend to select forbs, consuming large quantities and a wide diversity. Generally, sheep do little damage to riparian habitats. Goats prefer shrubs, including many thorny species. Only Texas has large numbers of goats (9).

Horses select grasses and use relatively small amounts of other plants (9). Burros, however, are highly indiscriminate in feeding, and when the supply of palatable plants is exhausted, they turn to unpalatable species. They even feed on creosote bush, which is so unpalatable that no other mammal is known to take more than an occasional nip of it. Also, burros do more damage by being wasteful feeders. Often they pull entire plants (roots and all), take a bite or two, and discard the rest (45).

Despite food preferences, grazing animals can thrive on virtually any kind of plant and will accept diverse food plants when normal preferences cannot be exercised (9).

Effects on vegetation.

The basic components of wildlife habitat are food, water, and cover—arranged in a way useful to the organism. For highly mobile animals, such as birds, the components may be widely distributed. For less mobile species, the components must be nearby. Food must be of an acceptable kind, quantity, and quality, and must meet the minimal nutritional requirements of the organism. Overgrazing by livestock often destroys or degrades one or more of these essential habitat requirements.

Because the native vegetation has been drastically altered in the past 100 years, few pristine areas remain in rangeland ecosystems, and it is difficult to reconstruct original conditions. Spring livestock grazing has severely trampled ranges. Today, the soils of many western ranges are saturated after the spring thaw. The hooves of livestock, especially cattle, churn the soil, creating a rough surface. Young and small plants tend to be destroyed directly, while older and larger grasses and forbs may be injured or destroyed by root damage, substrate disturbance, or loss of soil.

Prolonged selective consumption of the most palatable plants by livestock is detrimental to ranges. Sustained use and injury place the most palatable species at a long-term competitive disadvantage in rangeland plant communities, and species less affected by grazing tend to increase at the expense of those that are heavily used. Feeding by herbivores, whether wild or domestic, suppresses preferred food plants. This suppression of a few highly palatable species is a subtle change and not readily discernible by the casual observer.

Intensive cattle grazing has been responsible for changing vast regions of western grasslands into shrublands, thereby reducing the carrying capacity of these lands for native grazers such as bison and bighorn sheep (17). Such changes are partially responsible for the disappearance of bighorn sheep from much of their original range (17).

Continued grazing of "bread and butter" plants reduces vigor. If 30 to 50% of a plant is grazed annually, the plant is stressed (46). Once palatable species are lost, many years may be required for the range to recover. On an area in Arizona, without livestock grazing for 30 years, perennial grasses had not been restored (47).

Stocking rates on public lands are often set as allowable AUM's on a grazing unit based on total acreage. Unfortunately, cattle do not distribute themselves evenly over an entire acreage, and most favorable sites, such as stream bottoms may be subjected to severe overgrazing. Loss of riparian vegetation, soil erosion, and trampling of banks result (17). Most wildlife in the United States either depends on wetland-riparian areas or uses them relatively more than other habitats. Wetland-riparian areas are fragile and represent an extremely small percentage of the total land area in the West (48).

Several investigators have studied riparian habitat, after the exclusion of livestock. A description of Camp Creek (Oregon) in 1875 pictured the valley floor as meadowland with scattered marshes. Only 28 years later, the valley contained gullies and arroyos 15 to 25 feet deep and 25 to 100 feet wide. In the mid-1960's, about a mile of the eroded and gullied stream bottom was fenced to exclude livestock and to permit vegetation recovery. An additional 3 miles were fenced between 1969 and 1974. Of 45 plant species identified and found abundantly within the fenced area, only 17 were present before fencing. Water samples taken in February 1972, February 1973, and November 1973 showed a reduction in sediment load of 79%, 48%, and 69%, respectively, after flowing through 3.5 miles of protected channel. Sediment retention rebuilt the stream bottom and led to a rise in the water table. At one point in the stream, 36 inches of sediments had deposited. The first beaver was seen in 1971, and dams were present in 1972. Waterfowl were rarely seen before fencing, but since 1969, four to six pairs of nesting ducks have used the area each year. Also, 12 species of mammals occur within the exclosure (49).

Along Mahogany Creek in northwestern Nevada complete removal of livestock by fencing significantly improved riparian habitat (50).

At Big Creek (Utah), riparian vegetation, particularly sedges and grasses, enjoyed a marked recovery inside an exclosure between 1970 and 1974. But in 1975, trespassing livestock (6 weeks in May and June) eliminated woody vegetation and diminished grasses and sedges to the pre-fencing level. Stabilized streambanks were refractured and again began falling into the creek; overhanging banks, which provided cover for fish, were destroyed. Also, vegetative cover and soil stability ratings declined 35 and 14%, respectively. Since the 1975 trespass, the sedge-grass complex and streambank stability have resumed recovery, and by 1978, had regained the 1974 status. Use and diversity of small mammals, raptors, and songbirds have increased by 350% within the exclosure (51).

Grazing impacts on vegetation have been dramatic on many western rangelands. Sagebrush and other shrubs have encroached upon former grasslands, especially in valleys where the water table has been lowered by stream cutting. In the desert grasslands of the Southwest, shrub and tree invasions are extensive (25). In many regions, deep-rooted bunchgrasses have been eliminated and replaced with shallow-rooted annuals such as cheatgrass. Exotic forbs have invaded most ranges. No doubt, many species of plants were extirpated before they could be described. Other species of plants are rare or restricted in current distribution, and federal efforts to protect them from domestic grazing are totally inadequate.

Many animals preferring riparian habitat have been severely affected by loss of nesting and wintering cover. The western subspecies of the Yellow Warbler (Dendroica petechia) was recently put on the National Audubon Society's Blue List for declining species. The bird is highly dependent upon riparian habitat for nesting. According to Phillips et al. (52), the southwestern subspecies of the Yellow Warbler was eliminated from southern Arizona. However, when the Nature Conservancy purchased Sonoita Creek and fenced it against livestock grazing, the Yellow Warbler reappeared and became common within fenced portions of the stream.

Species inhabiting grasslands, such as the Vesper Sparrow (*Pooecetes gramineus*) and Western Meadowlark (*Sturnella neglecta*) have suffered losses of habitat when sagebrush invaded grasslands. Other species, however, have benefitted from this encroachment—Brewer's Sparrows, Sage Sparrows, and Sage Thrashers have probably increased. Sage Grouse require sagebrush and have not fared as well. Young grouse feed extensively on forbs (53) that have been reduced by overgrazing. This has apparently contributed to the decline of the species.

Effects on soil and watersheds.

As the quantity and quality of vegetation decrease, soil erosion increases. Overgrazing leads to bare and unstable soils, increasing temperatures, and losses of topsoil. These conditions are familiar sights in the western states and are well documented. More subtle changes in soils occur, but are mentioned less frequently. Continuous use by livestock causes soil compaction. When precipitation falls on compacted soils, percolation into the soil is retarded and much of the precipitation is lost to runoff. Because many western rangelands are arid or semi-arid, water is a valuable resource. Grazing affects infiltration, or percolation rates, by reducing protective vegetative cover, by reducing and scattering litter, and by compacting soils (9).

Infiltration rates in South Dakota on areas of similar soil type were directly related to the quantity of plants and litter. On ungrazed range on the southern Great Plains, infiltration rates were nearly four times those of grazed ranges of similar character (54). On a watershed in North Carolina, after 9 years of heavy grazing by cattle, soil pore space in the top 2 inches of soil was reduced 44% and in the next 2 inches by 60% (9). The extent of compaction after 100 years of overgrazing on western ranges is cause for concern.

Soil fertility may be altered by ways other than topsoil removal. Neal (55) found that increased numbers of invading plants may inhibit nitrogen-fixing bacteria. In contrast, no inhibition was found among stands of six dominant grasses.

Serious wind erosion is confined mainly to arid regions where precipitation is less than 15 inches. In such regions, erosion is encouraged by sparse vegetation and high wind velocity. Topographical irregularities and vegetation decrease wind velocities; vegetation is the most important factor in regulating wind transport of soil (9). Once vegetative cover has been damaged or removed, topsoil becomes unstable. In many heavily grazed parts of the western United States, soil "blow-outs" continue to occur.

Drastic changes in western ecosystems since the introduction of livestock may be partially a function of temperature. Little information is available on the influence of grazing at high elevations, but the general view is that the impact is diminished by adequate precipitation. Biological and physical alterations, however, are most extreme in the hot, arid Southwest. There, in the desert grasslands, severe gullying and losses of up to 3 inches of topsoil by sheet erosion have taken place (17). In Arizona, gullies initiated by overgrazing had not begun to heal after 40-50 years of complete protection from grazing (47). According to Odum (46), landscape ecology in large areas of the United States is determined by beef cattle.

The specific effects of overgrazing and soil compaction, loss of topsoil, and vegetation changes upon soil temperatures are poorly understood. Soil temperatures are higher on denuded areas than on areas having vegetative cover and abundant ground litter. Soil temperatures influence soil organisms—both adversely and beneficially—depending upon the organism and range of temperatures (e.g., some grasshopper eggs hatch earlier in the spring on denuded soils).

Expanding deserts are attracting worldwide attention. Researching the process of desertification is a recent undertaking, and droughts in arid and semi-arid regions are of special interest. Numerous theories have been proposed to account for the spread of deserts. A United Nation's conference on the subject, however, cited the grazing of domestic livestock as the prime cause, and identified the interior West as a potential candidate area for future spread of deserts. Parts of Arizona and New Mexico that were set aside for the Navajo Indians represent prime examples of desertification in the United States. Early travelers in the mid-19th century described these lands as consisting of lush meadows carpeted with grass. Traditionally, Navajo herders moved livestock between mountain summer ranges and lowland winter ranges. The major cause of the present deterioration of the reservation is overgrazing. Efforts to reduce livestock grazing pressure have met with strong resistance from the tribe, and reduction of livestock numbers remains an unpopular issue (56).

Similar resistance is often encountered among western livestock operators when attempts are made to reduce livestock numbers on overgrazed public ranges. Odum (46) states, "One is impressed with the mechanisms in nature that control or reduce grazing, just as one is unimpressed with man's past ability to control his own grazing animals, since it is increasingly evident that overgrazing has contributed to the decline of past civilizations."

As livestock have trampled and compacted soils and as high quality, deep-rooted plants have given way to shallow-rooted species, infiltration of water into deep soils has diminished. Surface runoff has increased. As water and wind erosion stripped natural ecosystems of topsoils, water quality declined as displaced soils silted streams and rivers (57). Because of silting, 21% of the nation's water-supply reservoirs will have a useful life span of less than 50 years, and another 25% will last only 50 to 100 years, according to Soil Conservation Service estimates. In 100 years, only 54% will provide enough storage capacity to meet present requirements (3).

Before the Civil War, the San Pedro and Santa Cruz rivers, and their tributaries in southern Arizona, coursed along through grass-choked valleys dotted with marshes and pools. Beaver dams were numerous, and trout were abundant, some up to 18 inches long. Today, these rivers flow intermittently, and much of the time, the beds are dry, sandy wastelands with sparse vegetation. Vertical banks along the channels drop 5 to 30 feet below the surrounding terrain. During the summer rainy season, flash floods sometimes fill the channels from bank to bank with a raging, muddy torrent (25). Bryan (58) concluded that the current cycle of erosion began in Arizona, New Mexico, Utah, and Colorado between 1860 and 1900, but more recent information restricts the onset to the 20-year period between 1875 and 1895 (25). That period corresponds closely to the time when livestock grazing was building toward a peak in the area.

Excessive quantities of fine sediments change the nature of aquatic systems, diminish productivity, and reduce the availability of fish spawning beds. Rangelands account for 28% of the annual sedimentation, being second only to croplands in sediment production (57).

In Rock Creek (Montana) the quantity of brown trout (Salmo trutta) was

32.5% larger in a section of stream passing through ungrazed lands than in a grazed section. Also, streamside cover was 76.4% greater, the channel was deeper and narrower, and riffles (used as spawning beds) were more numerous in the ungrazed section of stream (59). Similar findings have been reported in Oregon, Idaho, and elsewhere.

Overgrazing riparian vegetation and excessive sedimentation suppress fish production. Specific causes include elevated water temperatures, burial of fish foods and spawning beds by sediments, and reduced aeration and flow rates. Game fish, like trout, are reduced or eliminated and replaced by hardy, but less desirable species (e.g., chubs, squaw fish, etc.) that can survive in low quality streams. Grazing also intensifies bacterial pollution: the coliform group; fecal coliform bacteria; and fecal streptococci. In a small mountain stream, all three types were highest in the evening and lowest in the afternoon, because rising stream levels in the early evening flushed the streambanks. Coliform groups were most abundant during peak runoff periods in the spring; streptococci concentrations were highest at mid-summer when flow was minimal (57). Few western streams remain safe for direct human consumption.

Grazing is detrimental to other aquatic ecosystems. Many of these are wetlands important to waterfowl, marshbird, and shorebird reproduction. At least 55 studies of waterfowl have shown grazing to be detrimental to production. Weller et al. (60) concluded that cattle grazing on a waterfowl production area in Utah was as serious as the lack of water. On Malheur National Wildlife Refuge in Oregon, Greater Sandhill Crane (*Grus canadensis tabida*) nesting success has consistently been about 20% higher on ungrazed meadows (Littlefield, unpubl. data). In 1948, duck production was 150,000 on Malheur Refuge, but in 1974 only 21,300 were produced. In 1948, AUM's for cattle on the refuge were 74,385, increasing to 101,726 in 1951, and 123,807 in 1971. Although one cannot say conclusively that the decline in waterfowl production was caused by increased grazing, a large body of published evidence supports such a conclusion.

Many kinds of wildlife on wetlands require residual vegetation from the preceding year for nesting cover. Livestock grazing eliminates this cover and contributes to reproductive failures. Where livestock grazing occurs on U. S. National Wildlife Refuges, grazing programs should be carefully reviewed. Current grazing policy states, "Grazing and haying activities may be permitted on a secondary basis when these activities wisely utilize a renewable natural resource and do not conflict with established wildlife management objectives. Grazing and haying must be phased out as quickly as possible when such practices conflict with established wildlife management or habitat objectives."

Livestock grazing on National Wildlife Refuges should be reduced to levels compatible with refuge objectives. The timing of grazing is critical, and all summer grazing in production areas should be eliminated. Winter grazing should only be used to attain desired goals in habitat manipulation. Refuges should not be managed for the production of livestock (61).

Effects of livestock grazing on wildlife.

Livestock grazing and wildlife relationships have recently attracted considerable attention. No species can survive for long without food, water, and cover. A few desert rodents and birds can survive without free water, but most animals cannot.

As the most palatable plant species disappear from depleted ranges, competition for food is most critical between big game and livestock. Two species of big game are so incompatible with livestock that they will often leave an area when cattle appear. In Utah, Wilson (40) reported that desert bighorn sheep disappeared from Red Canyon in the southern part of the state in 1887 when cattle arrived. Cattle were removed in 1974, and within 6 months, bighorns returned. In another study in Utah where bighorns were well established, 30 cattle were brought in, but removed within a month. After the cattle were removed, no bighorns were seen for 8 months.

Mackie (39) observed that elk in Montana vacated lands occupied by large numbers of cattle. Similar elk behavior has been observed in Utah and Oregon (17, 62). In Arizona, a watershed was heavily used by elk after livestock were excluded. Use continued for 5 years, at which time cattle were reintroduced—thereafter elk have been conspicuously absent (29).

As man moved westward, elk disappeared from settled regions and vanished from most of their historic ranges. Remnant herds were left scattered in the Rocky Mountains and parts of the Pacific Northwest and Canada. Elk disappeared in the eastern United States early in the 1800's, and western herds reached a low in 1900 (18). Presently, there are about half a million elk in the United States versus an estimated 10 million in pre-settlement times.

Settlement of the West brought cities, agriculture, and a livestock industry, and elk were considered a nuisance (17). Elk are large, aggressive, and able to damage fences, haystacks, orchards, and golf courses. In Utah a State Board of Elk Control was established in the early 1900's to control nuisance animals. Control and overshooting nearly extirpated elk herds within the state, and the present population was derived largely from reintroductions from Yellowstone National Park, Wyoming. Today, there are about 13,000 elk in Utah. In a state having 80,000 square miles and 2 million livestock, why are there only 13,000 elk? The answer is that elk cannot be allowed to increase at a time when ranchers are being asked to reduce livestock quotas on public lands. The livestock industry is central in resisting increases of elk (17).

Bighorn sheep have suffered declining numbers and drastic range reductions. Bighorns prefer grass and thrive best on habitat dominated by healthy stands of native grasses. Extreme overgrazing, a standard practice during the early decades of the western livestock industry, eliminated perennial grasses from most desert ranges and unquestionably had a profound influence upon the survival of bighorn sheep (63). Whereas bighorns formerly occupied extensive areas, including lowlands, they are now restricted to rugged and rocky mountainous regions where little or no cattle grazing occurs. Current estimates of bighorns total 20,410—a shameful reduction from the 1 to 2 million estimated for pre-Columbian times (17).

When white man arrived in the West about 200 years ago, mule deer were scarce. The lush ranges that existed before livestock arrived were not prime deer habitat—deer prefer shrubs—not grasses. Intensive livestock grazing has reduced grasses and encouraged shrubs, thereby improving deer habitat. Some authorities credit the marked increase in deer during the first half of the 20th century, at least in part, to livestock grazing. Fires and logging have also been a factor. Gallizioli (64) states that if deer ever benefitted from overgrazing, the beneficial effects were short-lived. In Arizona, at least, range conditions today are generally so bad that severe competition exists between cattle and deer.

Gallizioli cites pellet counts used to measure deer use on two National Forests. On Tonto National Forest use varied from none (no pellet groups) on areas which had 500 to 900 cattle droppings per acre, to a high of 160 deer pellet groups per acre where cow droppings numbered less than 100 per acre. On Apache-Sitgreaves National Forest, in an area ungrazed by livestock an average of 103 deer pellet groups were found, but as few as 27 per acre on lands where more than 55% plant use had occurred.

Most American pronghorns share rangelands with livestock. According to some observers, today's cattle have replaced the bison of former times. Competition is not a problem on good ranges, but can be more severe on overgrazed or poor ranges. Originally, North America had an estimated 40 to 60 million pronghorns. By 1900, some authorities were predicting that the species was doomed to extinction. However, major conservation efforts increased the population from about 26,600 to an estimated 364,000 in 1964. Although pronghorns currently inhabit all western states, most (68%) occur in the shortgrass prairies in Montana, Wyoming, the Dakotas, Colorado, and New Mexico. About 31% are in Idaho, Oregon, and California; about 1% occur elsewhere (65).

Large carnivores that prey on livestock have been severely persecuted by or in behalf of the industry. Those species that were unable to adapt to human activities have been largely eliminated. Excluding Alaska, few wolves have survived in the United States. Today, grizzly bears persist only in remote isolated regions and in National Parks. According to Storer and Tevis (20), grizzly bears disappeared from Oregon in 1894, Texas in 1890, Arizona, New Mexico, and Utah about 1922, and California in 1924.

The coyote has survived and increased since settlement of the West. Killing livestock predators, especially coyotes, has been a long-standing policy of the federal government. Today, predator control is a responsibility of the Division of Animal Damage Control (ADC) of the U. S. Fish and Wildlife Service. ADC predator control in 15 western states cost taxpayers more than $10 million in 1978 (66). When a large herbivore population exists, large carnivore populations will naturally be attracted. This "cause and effect" relationship will persist as long as livestock graze western ranges. However, the willingness of the nation's taxpayers to continue to support a program financially beneficial to a select few who graze livestock on public lands is far less certain.

Besides big game and carnivore populations, other wildlife species, such as upland game birds, have experienced declines. Most grassland species have suffered marked reductions in distribution and abundance (67). Montezuma Quail (Cyrtonyx montezumae) have declined or been extirpated on much of their former range in Texas, largely because of overgrazing. Today these quail are primarily restricted to national forests and other regulated grazing lands in Arizona and New Mexico (67). Grazing actually increases the quail's major food plants, but destroys perennial grass cover needed for survival and nesting (64).

Modification and destruction of semi-desert grasslands have eliminated the Scaled Quail (Callipepla squamata) from peripheral portions of its range in Arizona and other localities. Also, circumstantial, but overwhelming evidence relates the demise of the Masked Bobwhite in Arizona and Sonora to heavy grazing (67). In California, Leopold (68) blamed overgrazing for a marked reduction in California Quail (Lophortyx californica) populations during the past 75 years.

A study of Turkeys (Meleagris gallopavo) in Arizona compared the survival of young on heavily grazed and ungrazed lands. The results showed 580 young per 100 females on ungrazed plots, compared to 150 young per 100 females on grazed plots. Reduced nesting and escape cover were believed to be responsible for the difference (64).

Blue Grouse (Dendragapus obscurus), a woodland species, are adversely affected when heavy grazing impoverishes or destroys brood cover (69). In Washington, the proportion of successful breeding females seemed to be higher on ungrazed habitat (70).

The production of Greater Prairie Chickens (Tympanuchus cupido) and Sharp-tailed Grouse (T. phasianellus) was reduced by annual grazing or haying—activities which reduce the quality of residual cover. The importance of abundant cover for these two species is well documented (1).

Several investigations of non-game birds have shown harmful effects of livestock grazing. Kirsh and Higgins (71) reported that Upland Sandpipers (Bartramia longicauda) had 71% nesting success on ungrazed prairie, but only 48% success on grazed prairie. In North Dakota, Duebbert and Lokemoen (72) found nests of 38 American Bitterns (Botaurus lentiginosus), 2 Marsh Hawks (Circus cyaneus), and 6 Short-eared Owls (Asio flammeus) in fields of undisturbed, tall, dense grasses and legumes, but 12 years of nesting studies on annually grazed grasslands indicated that these species avoided nesting in grazed habitat. Of 10 Marsh Hawk nests found on Malheur National Wildlife Refuge in 1980, all were in ungrazed meadows (Littlefield and Thompson, unpubl. data).

Meadow voles (Microtis spp.) are more numerous in ungrazed meadows. On Malheur Refuge these voles are a major food for various raptors. Rough-leggged Hawks (Buteo lagopus) and Marsh Hawks spend 74% of their feeding time over ungrazed meadows (Littlefield and Thompson, unpubl. data). In Idaho, Brewer's Sparrows increased 301% and Vesper Sparrows 170% a year after grazing was terminated (73).

Some investigators have observed an increase in rodents and rabbits in overgrazed habitats. Other investigators consider these increases to be short-lived, and point out that prolonged grazing abuses lead to severe soil erosion and eventually reduce the quality of habitat—even for jackrabbits and kangaroo rats. In a lightly grazed plot on Apache-Sitgreaves National

Forest, Arizona, the total rodent population was roughly twice as large as on heavily grazed plots (64). In the Grand Canyon (Arizona), Carothers et al. (74) found a greater diversity and larger number of small mammals on an area devoid of burros, compared to an adjacent area heavily grazed by burros.

Few, if any, groups of animals seem to be totally immune to the adverse effects of livestock grazing. In the Mojave Desert of California, horned lizards (*Phrynosoma platyrhinos*) and leopard lizards (*Crotaphytus wislizenii*) were absent on grazed land (43). In Idaho, the sagebrush lizard (*Sceloporus graciosus*) was most abundant in native, ungrazed habitat (42). In the Southwest, the trampling of young desert tortoises and burrows by livestock have been reported. Also, cattle and sheep damage tortoise food plants and harm shrubs used for concealment and cover (44).

A few species seem to benefit from overgrazing. The Horned Lark (*Eremophila alpestris*), known as the Shore Lark in Europe, prefers heavily grazed areas. The species is attracted to barren places, and overgrazing provides such habitat. Kangaroo rats also prefer moderately grazed areas, as do a few other small mammals. The zebra-tailed lizard (*Callisaurus draconoides*) was twice as abundant on grazed portions of the Mojave Desert. The species prefers washes, sites with small rocks, and hardpan supporting scant plant growth (43). In Idaho, the short-horned lizard (*Phrynosoma douglassi*) was most plentiful in an area dominated by sagebrush and grazed by sheep (42).

In the spring, mowed and grazed meadows may provide feeding and loafing habitat for migratory waterfowl, marshbirds, and shorebirds. Meadows in the process of being flood irrigated provide ideal feeding areas for northbound migrants. In the fall, when these same meadows are dry, they provide favorable habitat for raptors.

In summary, the long-term benefits of overgrazing seem few--if any.

Effects of Technology and Management

Grazing and related legislation.

By the close of the 1800's, unrestricted grazing had depleted much of the public rangelands. Harsh winters, severe droughts, and deteriorating range conditions had crippled the livestock industry—it became increasingly clear that regulation of the use of public lands was necessary.

Prolonged debate and realistic concerns about the condition of public rangelands led to the passage of the Taylor Grazing Act (TGA) in 1934. This was the first legislation designed to regulate livestock grazing on public lands. Under the TGA, grazing districts were created and efforts made to bring livestock use into balance with range capacity. Because of its narrow focus on livestock grazing and its restricted constituency (livestockmen), the act was ineffective. Increased interest in public land resources during the 1960's fostered concepts of multiple use management and led to the Classification and Multiple Use Act of 1964. Despite these acts and others, by 1974 roughly 135 million acres of the 170 million acres of BLM rangelands were still in fair or worse condition.

In 1971, Congress passed the Wild Free-Roaming Horse and Burro Act. The act proclaimed that these feral animals would have a permanent place on public lands and that their requirements would be included in the forage production base.

The Federal Land Policy and Management Act (FLPMA) of 1976 required federal agencies to protect and manage public lands for a wide range of benefits under principles of multiple use and sustained yield. The act provided for public lands to be retained in federal ownership, and specified, for the first time, principles for the management of public grazing lands. To deal with the plight of the nation's rangelands, in 1978 Congress passed the Public Rangeland Improvement Act (PRIA). After half a century of uneven federal involvement, Congress found that: (1) the rangelands were still producing below their potential; (2) they would remain in unsatisfactory condition or decline even further under present levels of funding for management, and (3) the unsatisfactory condition of the public rangelands presented a high risk for soil loss, siltation, desertification, water loss, loss of fish and wildlife habitat, loss of forage for livestock and other grazing animals, degradation of water quality, flood danger, and threats to local economies. To reverse this trend, Congress authorized an intensive rangeland management and improvement program and backed the mandate with an authorized investment of $365 million over the next 20 years.

Along with these congressional initiatives, the BLM was required by court order to prepare 144 individual Environmental Impact Statements, covering BLM lands grazed by livestock. In 1974, the Natural Resources Defense Council (NRDC) won a suit against the BLM for violating the National Environmental Policy Act (NEPA) and failing to prepare adequate and specific environmental impact statements for livestock grazing on BLM-administered lands.

The Public Rangelands Improvement Act and 1978 amendments to the Sikes Act direct the BLM to place special emphasis on improving and managing basic soil, water, wildlife, and vegetation resources to enhance these for various public uses (75).

Past practices.

Today, lands within BLM grazing districts continue to be managed for a dominant use—livestock grazing. Before passage of the Taylor Grazing Act, stockmen ran as many livestock as they wished on public ranges, and there was no reason to do otherwise. The Taylor Grazing Act failed to deal with the issues of excessive stocking and deteriorating range conditions. The BLM admits that 83% of its lands in 11 western states is in unsatisfactory condition. The agency is well aware of overgrazing and is attempting to improve management of rangelands (76).

All efforts by the BLM and USFS to increase grazing fees have met stiff resistance from the livestock industry, and in the 1940's, this issue led to the demise of the Grazing Service. There seems to be little chance that livestockmen will ever be required to pay a true market value for public forage. The western livestock industry, through district, state, and national advisory boards and through influence upon elected representatives, has severely restricted BLM management options. An example of such pressure is illustrated by the actions of a local BLM advisory board in southeastern Oregon. During a 15-year period, the board resisted all efforts of the Grazing Service, and later the BLM, to adjust grazing to the carrying capacity indicated in range surveys. Grazing permits had been set at twice the carrying capacity. A succession of BLM district managers who opposed the district advisory board were sacked. When a district manager was finally backed by BLM supervisors, including the director, the local operators expanded the conflict to the congressional level. The following letter was sent to the Secretary of Interior by the local board: "The thing which bothers us the most is that the (District Manager) made the cut against the advice of and contrary to the wishes of the Advisory Board. These men (the Advisory Board) are all experienced stockmen—all are operators—they know the range capabilities—they are interested, even more than the Manager, in a long time operation. Certainly it was never the intention of Congress that this one bureaucrat should override the considered judgement of the cumulated experience of the members of the Advisory Board. The manager and his paid personnel should furnish the information and the board should fix the policy. If this is not theory, it should be."

The inability of federal agencies to make management decisions in the public interest without unwarranted interference from the livestock industry has aggravated and continues to hamper the management of western rangelands (76, 77).

Some government agencies disguise grazing problems under euphemisms such as "using grazing as a management tool." The U. S. Fish and Wildlife Service is guilty of this ploy. Possibly, some refuges in the prairie states can use cattle to open or remove dense stands of bluegrass (*Poa spp.*), but refuges in the arid West have little basis for using livestock in habitat management. Sufficient data are available on the detrimental effects of livestock grazing on wildlife populations to contradict the claimed benefits of grazing. Vegetation rarely becomes so dense that it must be "manipulated" with livestock. Furthermore, the fencing costs, counting cattle, and permittee dependence weigh strongly against grazing programs. On Malheur National Wildlife Refuge, there are over 600 miles of barbed-wire fences. These fences are expensive hazards to wildlife and contribute nothing to sound wildlife management. Pronghorns, mule deer, waterfowl, Sandhill Cranes, owls, hawks, and other wildlife have been killed at Malheur by colliding or being entangled in fences. A juvenile Whooping Crane (*Grus americana*) was killed in Colorado after flying into a fence. The leading cause of mortality of moose calves (*Alces americana*) on Red Rock Lake National Wildlife Refuge (Montana) is entanglement in fences—numerous other examples of wildlife losses to fences are documented (61).

Grazing advocates on refuges are hard pressed to show convincing evidence that livestock grazing is a management "tool." Kirsh et al. (1) found that the frequency of grazing tends to be proportional to the productivity of the site. In the tall-grass prairie, where soils are fertile and precipitation adequate (20-30 inches), grazing might be permissible every 2 to 4 years. In the xeric (dry) mixed-grass prairie, where annual precipitation is 12 to 15 inches, grazing is possible only at less frequent intervals. In xeric desert or semi-desert grasslands, it is not likely that grazing could be justified at all. At Malheur Refuge, in a semi-desert region, grazing is attempted every 4 years, and many habitats and wildlife management areas remain in a degraded condition from previous mismanagement, and undesirable plants continue to invade. In this locality, a prolonged period of restoration may be required before livestock grazing can be effectively used again.

Fire is a natural factor on wild lands. No rangeland plant community has developed without its influence. Early on, the livestock industry developed a negative attitude toward fires. This has contributed to a broad policy of total fire prevention and suppression and has almost eliminated the use of fire as a management technique on rangelands (5). Millions of dollars of taxpayers money have been spent controlling fires. Nevertheless, many range scientists recognized the value of fire and the disadvantages of fire suppression. Fortunately a more sensible attitude toward fires seems to be evolving (5).

Past grazing practices, inadequate funding, and pressure tactics against agency personnel by the livestock industry have combined to degrade public grazing lands. Almost half the lands managed by the BLM are eroding at unacceptable rates and have declining wildlife habitats. Furthermore, about 77% of the fish habitat is in a static or declining condition. These conditions led the Natural Resources Defense Council (NRDC) to bring suit against the BLM. NRDC was not opposed to livestock grazing on the public lands, but believed that better grazing management was urgently needed (78). Something had to be done to stop further degradation of western rangelands.

Current Practices.

Since 1934, specific grazing tracts have been allotted to individual permittees. This allotment system was an effort to halt "nomadic" uses of public lands and to bring grazing into balance with the productive capacity of the range. Even though range abuse diminished, range condition continued to decline. Gallizioli (63) compared the degradation of western rangelands with a burning building: "...If the firefighters succeed in reducing the level of the flames from 20 feet to 5 feet, that is an improvement, I guess, but if they cease efforts at that point and decide that they have improved the situation by 75 percent, this is not going to help that burning building very much. It is going to burn down anyway even though it's going to take it a little longer to do so."

When livestock graze throughout the year, range is most severely damaged. To reduce this damage, several grazing systems have been developed. One, the deferred system, delays grazing. The longer grazing is delayed, the greater the opportunity for new plants to become established or for older plants to increase their vigor (9). This system is used by the BLM after an area has been seeded to crested wheatgrass.

Rotation grazing involves subdividing the range into units and grazing one range unit, then another in succession. The system assumes that livestock in large numbers make more uniform use of the forage, and that a period of nonuse is beneficial to plants (9).

In the deferred-rotation system, grazing is deferred on one part of the range during one or more years—then by rotation, other areas are successively rested until all have had a turn. Longer rest periods may be advisable if the range is in poor condition. Rest-rotation grazing is a system whereby the deferred part of the range is completely rested for one year. It differs from deferred-rotation in offering a longer period of rest, but heavier use when grazed (9).

The BLM is relying largely upon rest-rotation to solve overgrazing problems. The Bureau's decision (as reported in several published impact statements) to implement this controversial and expensive system has been criticized by the NRDC and numerous others, who question rest-rotation as a panacea. According to Wald (78) the system's benefits have yet to be demonstrated on such diverse lands as are managed by BLM. Many have urged the Bureau to reconsider its commitment to rest-rotation until the presumed benefits can be conclusively demonstrated. In the interim, it would be less expensive, less detrimental to rangelands, and more beneficial to wildlife populations if livestock numbers were reduced. No grazing system will be successful if riparian zones are unprotected. This was demonstrated at Big Creek (Utah) (51).

Associated with grazing systems are the so called range improvements. Although these improvements are often claimed to provide multiple use and wildlife benefits, most are strictly for livestock. Water developments are an example. No doubt, some species such as migrating birds do benefit. However, new water sources bring livestock into areas that formerly supported little or no grazing pressure, and many such areas experience rapid deterioration. Big game wintering in these areas and upland game birds nesting nearby certainly do not benefit.

The rest-rotation grazing system will require thousands of miles of new fences on western rangelands. Not only are fences extremely expensive but, as mentioned previously, detrimental to wildlife. In a survey of causes of mortality among desert bighorn sheep in Arizona, 12% (17 individuals) died as a direct result of fences (79).

One of the most destructive practices on BLM lands is the spraying of sagebrush (usually with 2,4-D) and planting of crested wheatgrass seedings. Little wildlife use occurs in these monocultural stands. Occasionally, pronghorns are seen on seedings, but they are also seen on highways—neither is considered ideal pronghorn habitat. Although a few other animals use crested wheatgrass seedings, only Horned Larks and black-tailed jackrabbits (*Lepus californicus*) do so consistently. Furthermore, jackrabbits use only the edges of seedings for foraging at night, and Horned Larks use them for roosting and foraging during the day, but rely on nearby sagebrush for shade and cover during mid-day (73). Burrowing Owls (*Speotyto cunicularia*) and Western Meadowlarks may be seen on seedings during the nesting season. Sage Sparrows, Brewer's Sparrows, and Sage Thrashers prefer sagebrush (73). In a study of Brewer's Sparrows in Wyoming, Schroeder and Sturges (80) reported a 67% decline and a 99% decline 1 and 2 years, respectively, after sage was sprayed. No nesting was found on the sprayed plot. In central Montana, Brewer's Sparrows declined 54% a year after spraying. Follow-up studies on this area (5 years later) revealed that the species was almost completely absent, and other species had not invaded (34). The species diversity and relative densities of nesting birds, non-nesting birds, reptiles, and large and small mammals were significantly lower on crested wheat seedings than on overgrazed sagebrush habitat (81). Numerous studies throughout the West have demonstrated the importance of sagebrush to Sage Grouse during all seasons (82, 83, etc.).

Extensive monocultures of crested wheatgrass are virtually biological deserts. Any shrub that invades such seedings, especially if it is unpalatable to livestock, is considered vermin. To eliminate these "wolf plants", 80% utilization per year is recommended (32). Obviously, such intensive livestock use ignores soil erosion, sedimentation, and other environmental considerations in the ecosystem. The solution to a minor problem may be creating a host of others.

Another widely used range improvement on public lands is brush control. Often the procedure has been used without regard for other environmental considerations. Usually, there was only one concern—livestock forage production (9). Only recently has wildlife been considered, and then only rarely. Large acreages of juniper-pinyon pine and mesquite have been killed with herbicides or mechanical methods. Extensive clearing has adversely affected many types of wildlife. However, Baker and Frischknecht (84) noted increases in small rodents after juniper removal and range reseeding in central Utah. Deer mice (Peromyscus maniculatus) and pocket mice (Perognathus parvus) increased in the first 2 years.

The total impact of brush clearing upon wildlife seems to depend upon the procedure. When large blocks of vegetation are removed, the effect is highly detrimental. In Texas, Beasom and Scifres (85) found that white-tailed deer numbers remained constant on an area in which strips of mesquite were sprayed. But when a solid block was sprayed, deer numbers dropped about 40% (15 to 27 months after spraying). In contrast, the number of deer increased about 100% on an unsprayed plot (for up to 21 months, but declined after 27 months). Wild turkey counts were somewhat variable, but showed a general increase on the unsprayed areas, and a decrease on the sprayed areas. Peccary (Pecari angulatus) were also more abundant on unsprayed lands, where their most important food, prickly pear, persisted.

Less is known about effects upon other forms of wildlife. Howard and Wolfe (86) reported that removing juniper deprived Ferruginous Hawks (Buteo regalis) of nesting sites. Pulich (87) concluded that juniper eradication in Texas has restricted the distribution of Ashe juniper (Juniperus ashei), a major habitat for the rare Golden-cheeked Warbler (Dendroica chrysoparia). Presumably, many songbirds that depend upon these trees and shrubs have been harmed.

When alternate cleared and uncleared strips (one-eighth mile wide) are left, most wildlife populations, especially deer, actually increase.

A "new" technique for controlling shrubs, especially sagebrush is gaining popularity—the use of fire. Recently, a controlled-burning project in southeastern Oregon demonstrated the advantage of fire. Burning was much cheaper (less than $1 per acre compared to $11 per acre for herbicides) and produced a desirable mix of burned and unburned habitats that will be attractive for wildlife. Past efforts by the BLM to leave strips of sagebrush in seedings have been ineffective, because of herbicide drift. The problem was eliminated with burning, for fires tend to burn in irregular patterns. Such irregularity creates a maximum of "edge effect" and habitat diversity (88).

Several National Wildlife Refuges have control burned for several years, and the vegetative and wildlife responses in meadow habitats have been desirable. In remote sections of National Parks and National Forest wilderness areas, many "natural" fires are allowed to burn themselves out.

Vegetative response to burning was studied in southeastern Oregon by Concannon (89). She found that native, perennial grasses, such as Sandberg's bluegrass and bluebunch wheatgrass, increased significantly after a burn; Idaho fescue fared less well. Where perennial grasses were depleted, cheatgrass gained temporary dominance after burns but receded later as perennial grasses returned.

In Wyoming, for four years after a burn, bighorn sheep and mule deer grazed the burned area more than adjacent unburned sites (90). Burning sacaton grass (Sporobolis wrightii) in Arizona led to more use by raptors, game birds

/especially Mourning Doves (Zenaidura macroura)7, and seed-eating birds. Also, burning greatly reduced cotton rat (Sigmodon hispidus) numbers, although seed-eating pocket mice (Perognathus spp.) and kangaroo rats (Dipodomys spp.) increased. Sacaton grass, even when burned in summer, recovered rapidly in the absence of livestock grazing. Fire seems to be beneficial to the indigenous plants and wildlife found in sacaton communities (91).

Ranchers have developed various techniques to increase winter feed for livestock. After grazing public lands through the summer, most livestock requires winter feeding. Hay and other winter feeds are often grown on private land. Fertilization of meadows, sophisticated haying equipment, and complex irrigation systems have helped to increase productivity and efficiency of these operations. Another method is to plow native meadows, which yield a single cutting per year, and plant alfalfa, which yields several cuttings.

The technologies used to produce winter feeds also affect wildlife. Early mowing (June and July) may be extremely detrimental. Interviews with mower operators on private land in southeastern Oregon in 1976 confirmed high mortality of young birds from July 1 to 15. Two operators thought they had killed 400 to 600 birds during a 2-week period. Most victims were shorebirds, but numerous waterfowl nests, young ducks, and Sandhill Crane chicks were also destroyed. One operator killed two pronghorn fawns (61).

With the introduction of sprinkler irrigation systems, many acres of native meadows and grasslands have been converted to alfalfa and other feeds. Most such conversions constitute a loss of valuable wildlife habitat.

Recent interest in public lands have compelled agencies to pay more attention to multiple uses. Although management agencies are required by law to practice multiple use, major emphasis continues to favor dominant users such as the livestock and timber industries. The Federal Land Policy and

Management Act of 1976 reversed the long-standing policy of land disposal and mandated that the public lands be retained under Federal ownership and managed for the national good under the principles of multiple use and sustained yield. The act changed public attitudes about public lands, for historically, these lands had often been viewed as private preserves for western stockmen and mining interests. FLPMA acknowledges the growing national recognition of the deteriorated condition of the public rangelands (75).

About 21,000 livestock operators graze some 9 million head of livestock on public lands. About 3% of the nation's cattle and 28% of the nation's sheep are grazed on public ranges. While these figures are not significant nationally, they are often central to the economic security and way of life of many western communities. Based on the 1980 fee of $2.36 per AUM, the grazing capacity of rangelands (about 13 million AUM's) amount to about $30 million worth of forage per year. According to a 1979 BLM report, if the presently deteriorated lands were improved to optimum productivity, livestock forage could be doubled in 15 to 20 years, and many other benefits of a productive range would also be increased substantially. Recent legislative actions have addressed improving rangeland productivity, and including funds from the Public Rangeland Improvement Act, as much as $750 million may be available over the next 20 years for range restoration.

In 1979, the BLM received a total of $68.6 million for range programs. Grazing fees paid by livestockmen for use of public ranges amounted to $20.8 million. In addition to the $68.6 million federal investment, 50% of the grazing fees were returned for range improvements—half to the district from which it came (92). American taxpayers pay $68.6 million for a $10.4 million return.

In 1979, the net grazing loss for the USFS was nearly $16 million.

According to the USFS, one federal job is created for every 2,200 AUM's. This amounts to about 8,000 jobs relating to grazing on public lands (93).

The question is, will taxpayers continue to be willing to support the small group of grazing permittees, whose livestock and livestock-related activities degrade public rangelands, while providing only 4% of the nation's red meat?

Future options.

The nation's rangelands have a productive potential estimated at 566 million AUM's of livestock grazing—more than 2.5 times the actual production in 1976. By applying intensive management on all available acres of range, the full potential might theoretically be achieved. However, this course would be terribly expensive and would disregard all other uses and values of rangelands. Applying intensive management to the currently grazed acres could bring forage production to within about 80% (about 450 million AUM's) of the full potential (94).

In 1976, ranges produced about 217 million AUM's, only about 2% more than 1970. Current trends indicate that by the year 2030 ranges could supply about 250 million AUM's. But as the nation's population increases, the projected demand for red meat of 450 million AUM's will exceed the anticipated supply by about 200 million AUM's (94). The BLM hopes to double forage production from 5.6 million tons to 11.2 million tons (75).

Can government agencies attain these production goals without further degradation of rangelands? Can such increases be accomplished without detracting from other uses of the nation's rangelands? Surely such intensive grazing programs will jeopardize multiple use management, especially if forage production is increased with massive seedings of crested wheatgrass. For rangelands to be made more productive through natural restoration, a major reduction in livestock is unavoidable. But projected increases in forage production and AUM's of the BLM and USFS would not permit reductions of livestock numbers. A total reliance upon intensive range improvements, without reducing livestock numbers, is environmentally unacceptable to many other users of public rangelands. Seedings, brush removal, fences, and new water holes will not meet the future needs of American wildlife.

Protecting riparian habitat, while continuing present grazing policies, will require hundreds of miles of fence. Construction costs ($2000 to $6000 per mile of stream), annual maintenance, and periodic replacement will demand large expenditures. The livestock industry rejects fencing as a practical solution, objects to livestock being fenced out of productive sites, and contends that fencing interferes with wildlife movements (95). Of course, the same could be said of all fences! But, if not fences—then what?

Many critics would like to see ranges seeded with native grasses, rather than crested wheatgrass. Native species would benefit wildlife, but could not support as much livestock use. The past has clearly shown that native grasses cannot sustain heavy grazing pressure. Presently, seed suppliers have not developed technologies to mass produce native seeds, but progress is being made. If land management agencies would create a demand for native grass seed, price and availability would no doubt improve rapidly. Planting a mixture of grasses, forbs, and shrubs would improve seedings for multiple use.

What alternatives are available to stop further degradation on western rangelands? Developing more forage on private lands would relieve some of the pressure, but costs and land availability are limitations. Alfalfa produces more forage per acre than native meadows, but the loss of wetland habitat would be detrimental to wildlife.

Another alternative is geographical diversification. The southeastern United States is an area with high potential for cattle ranching. The Southeast is not as fragile as the desert and arid ranges of the West and can boast the highest forage production in the United States. Cattle have done well in this region since the Spanish introduced them into Florida in the 16th century (96). Precipitation is high, topography gentle, and soils are deep—unlike most western rangelands. Under these conditions, the Southeast has a tremendous potential for livestock production, and increased production there would allow the West to begin mending from the severe abuses of the past.

Socioeconomic Factors

Commodity Interest.

Although we generally assume that underdeveloped nations are most dependent on food imports, it is the developed nations that place the greatest burden on exportable world food supplies. The United States imports more beef than any other nation. Almost half of this imported beef comes from the poorest, most protein-deficient sections of Central America—Costa Rica, Nicaragua, Honduras, and Guatemala—where per capita consumption of meat is increasing only slightly or else declining. In Costa Rica, while meat production increased 92%, meat consumption per capita declined 26%. In many underdeveloped countries, land suitable for local food production is being used to produce exportable livestock (97).

American livestock production involves an enormous waste of protein. The average steer gains only a pound of edible meat for each 7 pounds of grain consumed—the other 6 pounds being lost as energy, inedible portions of the carcass, or as waste products. Of 140 million tons of grain and soy fed to beef cattle, poultry, and hogs in 1971, only 20 million tons were converted to meat. American livestock now consume about one-half of our harvested grain. Even much of the grain that the United States exports does not go to underdeveloped countries for food, but to nations like Japan and Great Britain to feed livestock. Although protein is a precious commodity throughout the world, much of the world's protein supply is being converted to fat (97).

Before 1950, the nation's annual beef consumption had been fairly stable, at about 60 pounds per person. After 1950, meat consumption doubled. By 1977, beef consumption averaged about 126 pounds per person. Because the human body cannot store protein, excessive protein is either burned as an energy source or excreted. The nation could reduce its livestock population by 25% and still have enough to feed every person half a pound of meat or poultry a day—enough to meet our total protein requirements. And, of course, we also get large amounts of protein from other foods. Beef has become an American status symbol. In the late 1960's, beef ranked third behind cars and television sets as an item most desired by Americans (97).

The demand for beef has, to some extent, been created with surplus grains. Something had to be done with the embarassing surpluses, so Americans were introduced to feedlot beef. This change put additional pressures on rangelands—just to meet growing consumption. But by the mid-1970's, the situation had changed. With an increasing world population, American meat consumption became an extravagance. Currently, Americans use almost as much grain for "feed" as people in poorer countries eat directly as "food" (97). As world demands for protein become more acute and the price and alternative uses of grain increase, it will no longer be feasible to divert massive amounts of grain to livestock production.

There is a dire need for Americans to reduce their extravagant consumption of red meat—not just to lower demand upon grain. Vital rangelands are being stressed, and the quality of life, as embodied in multiple use concepts, is endangered by efforts to force the land to meet excessive production demands. Fragile western rangelands will be hard pressed to respond.

The current national options seem to be: (1) Reduced American beef consumption; (2) Livestock production in areas that will divert grazing pressures from western ecosystems; or (3) Increased meat imports. Because current levels of beef consumption represent an extravagant and wasteful luxury, this option holds great promise. An education program to alter diets and a policy to hold livestock production at the current level would have no great economic impacts. Many foods are as rich or richer than meat in protein. For example, meat contains about 25% protein and ranks in the middle of the protein content scale, along with various nuts, fish, cheeses, and beans. Many foods rank higher, with soybean flour containing 40% protein (97).

To relieve abuse on public ranges, private lands will have to be made more productive. Many western ranchers are already converting shrub uplands to alfalfa. But if beef demand continues to increase, private lands in the West will be unable to relieve significantly the demands for public forage.

The public has always displayed a willingness to accept certain environmental insults for the national good. However, because the livestock industry on public lands makes only a small contribution, requires large subsidies, causes abuse of public lands, and makes demands on vital grain supplies, continued public support for the industry will likely diminish with the passage of time. With increasing interest in multiple use, all grazing programs on public land will receive closer scrutiny. Certain conclusions seem indisputable—western rangelands cannot be made well with money alone, and sooner or later, use must be brought in line with carrying capacity and multiple use objectives.

Other uses of rangelands.

Livestock sales bring new money into local economies. This money is respent several times, extending economic benefits beyond the original sum. The multiplier effect of new money is estimated at 2.25. Annual livestock values derived from grazing on federal rangelands in the 11 western states is estimated at $390 million. If livestock were withdrawn from or severely reduced on federal lands, local and state economies would suffer (98). If livestock numbers increase, the economic returns from sales would naturally increase, but would do so at the expense of other uses and values on public lands. Recreational and wildlife values would suffer.

According to the National Survey of Fishing and Hunting (99), about 128 million Americans participated in one or more outdoor recreational activities in 1970. Almost 55 million fished, hunted, or both and spent 779 million days in recreation. Also, 7 million birdwatchers spent 432 million days afield, and 5 million wildlife photographers spent 40 million days. In 1970, the more ardent fishermen and hunters numbered more than 36 million and spent $7.1 billion on their sports. In 1970, there were 3 million more fishermen and hunters than in 1965, and they spent $3.1 billion more than in 1965. Such data indicate the impact of outdoor sports and recreation upon the socioeconomic structure of the nation. In the 11 western states, 51% of the people fished and 24% hunted in 1970. More than 25 million people hunted and/or fished in the 11 western states, and 2.4 million hunters sought game on public lands.

In 1978, 196 million people pursued recreational opportunities on BLM lands—camping, fishing, hiking, hunting, sightseeing, and other outdoor activities. In the West, these activities are dramatically increasing.

In 1979, the BLM spent $21.4 million on recreational programs, of which $9.9 million went for wilderness review (92). This $21.4 million benefited millions of the nation's citizens. On the other hand, the BLM spent $68.6 million on rangeland improvements, largely for the benefit of 21,000 permittees who produce about 3% of the nation's livestock.

Some local economies would suffer from a reduction in livestock on public lands. However, improved range conditions would foster recreational uses and partially offset the loss. Range improvements resulting from reduced grazing and the discontinued use of herbicides, could markedly increase fish and wildlife populations and improve recreational opportunities. Reducing siltation, prolonging the life of many western streams, rivers, and reservoirs, and insuring abundant supplies of high quality water for irrigation, hydroelectric power, and other downstream uses would bring other substantial economic benefits.

Conflicts.

To many critics, grazing permittees on federal grazing lands are a coddled welfare minority, but few would deny the political clout of this segment of the livestock industry. The current level of subsidy to ranchers and the damages sustained by public lands are strong arguments for reform. If grazing is only possible on public lands at a net loss, a choice must be made between withdrawing uneconomic rangeland from grazing and using the land for other multiple use purposes, or continuing to permit grazing at the taxpayer's expense (93).

Public subsidies to ranchers in 1979 were more than $60 million. To eliminate this loss, grazing fees would have to be dramatically increased, and the resulting fees would exceed what the ranchers would be willing to pay. If grazing fees were set to cover the costs, livestock numbers would significantly decline on public lands (92).

Ranchers argue that meat is a useful and demanded commodity and that government subsidies help provide this commodity to consumers at lower cost. But according to Handwerg (93), if consumers want meat produced on public land, they should be willing to pay the full price. Not all consumers eat meat. Many purposefully avoid meat produced on public land and object to supporting the western livestock industry with subsidies. Generous federal subsidies to the western livestock industry give it a competetive economic advantage over producers in other parts of the nation who produce 97% of the beef—without significant federal assistance and on private, taxed properties.

Arguments opposing public grazing subsidies include mention of high environmental costs such as erosion, diminished water quality, deterioration of fish and wildlife habitat, and others. Resentment against these welfare programs seems to be increasing, and as more people become aware of the problems and costs, resentment is bound to intensify.

A large proportion of the population lives in metropolitan areas, and portions of the West are rapidly becoming urbanized. Recreation interest is increasing. In a recent California survey, strong statewide support was found for efforts to protect and manage resources in the state's deserts. Special concern was voiced by residents of urban centers (92). As these population centers grow and more leisure time becomes available, more recreational use can be expected on public lands. These urban citizens will not be willing to share campgrounds with cows. Presently the fastest growing demands on public lands are for "non-consumptive" uses. Obviously, urban voters and non-consumptive users will become increasingly influential in determining land use policies.

At the request of Congress, the BLM is reviewing its public lands in the

11 western states to identify areas that may qualify for wilderness designation. By the close of 1980, the BLM will have reviewed 55 natural and pristine areas and 174 million acres of public lands for possible inclusion in the National Wilderness System (92). As of October 1, 1978, 175 federal wilderness areas (16.6 million acres) were in existence. The USFS administers 89%, the National Park Service 7%, and the USFWS 4% of these lands. The BLM had 12,000 acres in the system (94).

Although FLPMA allows the continuation of livestock grazing where it has been customary, the livestock industry has strongly opposed BLM wilderness, largely because motorized equipment and water developments are prohibited. The National Cattlemen's Association (NCA) opposes further wilderness designation and vigorously argues for continued management practices on and entry to all public rangelands (100).

Many ranchers tend to view trees and shrubs as merely taking up valuable space that could be growing grass. Consequently, thousands of acres have been sprayed or physically treated. Such procedures, especially if applied to large blocks of land, are highly detrimental to wildlife. Public concern has resulted in the use of several new techniques, such as strip-clearing and burning, Tree and brush removal pits livestockmen against many other environmental interests, and the controversy will surely intensify.

In southeastern New Mexico, ranchers are fighting to keep net-wire fences on their BLM grazing allotments. These allotments lie within a half-million acre region, west of Roswell, which was once home for the most productive pronghorn population in the Southwest. In 1940, some 3000 pronghorns occupied this region, but by 1976, less than 300 could be located. The sharp decline, according to wildlife biologists, was blamed on miles of net-wire fence that sheep ranchers put up in the 1930's and 1940's. In the semi-arid Southwest, pronghorns must move freely to find sufficient food and water. Domestic sheep and pronghorns enclosed in the same pasture vie for the same food plants, and severe competition results. Unlike cattle and sheep, pronghorns cannot survive on hay put out by ranchers during droughts. In 1965, BLM officials in Washington instructed New Mexico officials to reduce the impacts of net-wire fences. Since then about 300 miles of fences have been modified in New Mexico and four other states (101).

Rancher opposition has been immediate and forceful. They claimed the modified fences would lead to increased losses from predators, impede control of livestock, and lower the resale value of their ranches. They sought support in newspapers, the bureaucracy, and from politicians. As usual, whenever changes seem to threaten the livestock industry, the ranchers claimed that the federal government was encroaching upon state rights, coyotes would finish off the sheepman, ranchers are natural and knowledgeable conservationists, and pronghorns survive only because of net-wire fences. This episode was the first challenge to the effectiveness of FLPMA or the "Organic Act", which requires management of public lands for multiple use and sustained yield, and which somewhat impairs the long time cozy relationship between the BLM and grazing permittees. No doubt the ranchers will continue their objection, but not from behind a net-wire fence (101).

Of the many assaults by special interest groups upon national resources in America, none has been as self-serving as the "Great Land Grab" of the 1940's. An effort was made by a small, but politically powerful group of western stockmen to take title to immense tracts of federally owned grazing lands. This episode ended with a victory for conservation forces (102), but the victory celebration was short-lived.

Today, ranchers and other commodity interests are making another effort to take over public lands—both Forest Service and BLM lands—by having them transferred to the individual states. The current effort (the sagebrush rebellion) comes at a time when agency policies are in revision, multiple use concepts are gaining emphasis, grazing reductions are being made or considered, and traditional industry clout is being challenged. The "sagebrush rebellion" is actively opposed by conservation groups, who fear that if states gain title to public lands, state politicians, many of them part of the rebellion, would be easier to manipulate and more sympathetic to "Western ways." The so-called "sagebrush rebellion" represents greed at its worst—a small special interest group attempting to reach deeper into the public's pocketbook (103).

For years, the public has been waiting and watching for true multiple use to come to the western rangelands. Their patience is beginning to wear thin (101).

Conclusions

The data base is adequate for decision making by federal agencies managing public rangelands. In general, a need for further research is not a legitimate excuse for delaying range decisions. A more serious problem is getting the agencies to use information at hand. For example, the BLM continues to develop large seedings of exotic grasses, even though such seedings are clearly detrimental to wildlife and biologically unstable. It is a well known principle of biology that monocultures are excessively vulnerable to disease, parasites, and other negative interactions (46). Even now, wheatgrass bugs have begun attacking range seedings, and in Utah, at least 200,000 acres were affected in 1966 (32). Further emphasis upon vast seedings will surely bring greater difficulties. It seems only a matter of time until agencies will be wanting to spray seedings with insecticides.

The diets of Americans must change. Today, many bumper stickers read "eat more beef". The crisis on public rangelands suggests that "eat less beef" would be more appropriate, particularly when current consumption already approaches gluttony. According to recent evidence, too much meat in the diet may be unhealthful. Changing American eating habits might not be that difficult, for when a clear need exists, Americans are willing to change. Look what happened to large, gas-guzzling cars.

Multiple use concepts need to be reexamined. Conflicts are destined to increase, and the current system is not working. One option would be an effort to separate users according to the land's highest potential. A better solution would be a recognition of the true meaning of multiple use. In any event, the public is growing unhappy with the current dominance of commodity interests at the expense of all other considerations.

Excessive and intensive management for a single commodity interest, like livestock grazing, is becoming increasingly unacceptable to a growing urban population interested in recreational uses of public lands. These users will not be content to play second fiddle to a cow. The public is already becoming aware of the depleted condition of western ranges, and especially riparian habitats. During summer outings, people see the damaged streams and the omnipresent herefords. They see alpine meadows denuded by hundreds of grazing sheep, and they see the condition of semi-desert and desert grazing lands. The public's environmental savvy is rapidly improving—the livestock industry and management agencies will increasingly be less able to ignore acute criticisms.

As mentioned elsewhere, livestock on the western public ranges make only a minor contribution to the nation's red meat production. The cost of this small contribution in water quality, soil erosion, vegetative degradation, decreased wildlife production, and other environmental losses has been unacceptably high. We have to ask—is it worth it? The difference in year to year variation in livestock production in the United States sometimes exceeds the total contribution from public lands! Although continued modest grazing on public lands is permissible, past abuses are a luxury the nation can ill afford.

Future research should be directed toward determining the effects of grazing upon the whole ecosystem. Little information is available on soil compaction, soil loss, soil microorganisms, ground temperature regimes, and other ecological factors. Presently, information on major wildlife species is accumulating, but little information has been collected on the less conspicuous components of the ecosystem. Too often past research has concentrated on efforts to increase forage production, often on lands having low potential to begin with.

Today, employes of management agencies are trained in more diversified disciplines. If these younger employes survive the abuses of rancher and veteran agency personnel, they will ultimately create pressures for better management policies. New techniques and rapid change are already appearing.

Recent budget increases for range management have been approved by Congress. Unfortunately, these expenditures will be devoted to so-called range improvements, such as seedings and rest-rotation grazing systems. These efforts ignore everything we know about land husbandry and carrying capacity and assume that by spending huge sums, we can change reality and miraculously double production on tired, abused, and damaged rangelands. Congress and most others involved with rangeland issues have not been willing to bite the bullet. The only way to improve ranges is to drastically reduce livestock numbers. A sick patient needs rest! A century of range abuses and rancher domination of government agencies has hurt. Now, we must consider other alternatives—too much is at stake to do otherwise.

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Background Paper No. 21

A REVIEW OF CURRENT WATER EROSION CONTROL TECHNOLOGIES, INCLUDING POTENTIAL CHANGES TO ENHANCE THEIR EFFECTIVENESS

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October 1980

Office of Technology Assessment
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Background Paper No. 21

A Review of Current Water Erosion Control Technologies, Including Potential Changes to Enhance Their Effectiveness

by

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Summary:

The soil erosion process is discussed with particular attention given to the soils' resistance to erodibility. Erosion control practices are described. The principal emerging technology is predictive modeling to aid in planning the erosion control system. Recommendations include increasing support for research and additional technical staff, discontinuing the discontinuing the cost-sharing programs, and over-laying erosion control and water quality programs using major land resource areas.

The present form of erosion control programs in the United States has its roots in the 1930's. The pattern established then of a flexible program based on the voluntary cooperation of farmers, has changed very little.

The present and future directions of erosion control programs are in doubt. Federal Agencies have been chastised for not making a greater effort on urban erosion problems. Controlling urban erosion may improve water quality, but diverts technicians from agricultural areas. Soil conservation wisdom and practices are largely rural, so urban impacts and problems are approached on a piecemeal basis.

One of the most serious problems is how farmers percieve the value of land as determined by today's market. Agricultural land with conservation practices in place does not enjoy the price increase of irrigated or drained land.

Crop production levels have plateaued. For grain producers, the crucial variable is the export level. Expansion of production in response to rising demands will likely result in increased cultivation of fragile lands. The pressure on land resources in the western cornbelt will be particularly intense.

Farmers are confused by non-point pollution control programs supervised by the U.S. Environmental Protection Agency and various state agencies. The goal of these programs is to assure that agricultural activities involving the manipulation of soil and water resources do not pollute the nation's waterways. Regulatory programs being authorized may have significant economic impacts. There is a tradeoff between income and soil loss, especially in the short run.

This report discusses the erosion process and the effective erosion control practices. Consideration is given to emerging technology's ability to maintain productivity. Some suggestions are made with regard to regulatory, legislative, or institutional mechanisms to improve erosion control.

1.0 Description of Upland Erosion Process

Erosion is the removal of soil particles from their environment. Todays' soil conservation programs are walking a narrow line between the freedom of the individual farmer to conduct his business and the overall interest of society. A national program of soil erosion abatement will be more acceptible to farmers, if a flexible approach to erosion control is taken. The implementation of cost-effective practices will require a solid, basic understanding of the erosion process and current control techniques.

The erosion process can be broken into four phases -- the detachment of soil particles by raindrop impact, the detachment of soil particles by flowing water, the transport of detached particles by raindrop splash action, and the transport of detached particles by surface runoff.

Rainfall provides the major input of water and kinetic energy that drives the erosion process. It begins when soil particles are detached, and splashed in all directions from the point of raindrop impact. A net downslope movement results. When the rainfall rate exceeds the infiltration rate, depression storage is filled and overland flow begins. It normally moves a short distance as thinsheet flow or as interrill flow. The distance may be a few inches to about 100 feet. Concentration of the water in small channels, due to micro-relief, tillage marks, and/or previous erosion, is rill flow. The characteristics of the overland flow and erosion processes are different in several respects.

1.1 Interrill Erosion

Rainfall is the dominant erosive agent on interrill areas. Transport by raindrops is small, being approximately 5% of the total soil loss. Soil is splashed directly into the rills, uphill, downhill and kept suspended in surface flow on the interrill areas by rainfall.

Overland flow is usually shallow, has low velocities and very little capacity to detach soil. However, it transports loosened soil particles more effectively than rainfall. With the extra turbulence induced by falling raindrops, it will carry most of the detached soil to a rill or downslope.

1.2 Rill Erosion

Overland flow determines the erosion rate on rilled areas. As the surface runoff concentrates, the soil's ability to resist detachment is overcome and scouring proceeds. The susceptibility of a soil to rilling is determined by slope steepness and length, the runoff rate, its physical and chemical properties, and the vegetative cover. The size and number of rills are highly variable when highway banks, tilled farm fields, forests, grassed areas, and construction sites are compared.

1.3 Total Erosion

The combined effects of erosion from the interrill and rilled areas determine total erosion. Large volumes of soil cannot be moved without concentrated flow. The process by which the excess rainfall concentrates as surface runoff and the soil's susceptibility to rilling are important components.

The effect of slope length on erosion rates from cultivated slopes is to increase runoff with distance down from the top of the slope. Increasing flow rates will increase rill erosion on larger slopes, but interrill erosion is not influenced by slope length. The total soil loss rate will increase with distance depending on the relative contributions from interrill and rill erosion.

Nearly all the eroded soil will be from the interrill area near the top of the slope. Rill erosion increases rapidly with slope length, and at some point downslope, will become larger than that from the interrill area.

Erosion from the interrill areas will become almost constant with increasing length downslope and as the flow distances to rills become constant.

1.4 Soil's Resistance to the Erosive Action of Rainfall

Much has been written about the influence of texture, structure, organic matter content and other factors on a soil's erodibility. Investigators have usually measured the susceptibility of a soil to erosive forces rather than its resistance. A review of the research reports to determine a soil's resistance to the erosive action of rainfall concludes:

1. The rate of particle detachment by raindrop impact (soil splach) is a time-dependent function for any rainfall intensity.
2. The erosion resistance of a soil changes as its characteristics change during a rainfall event,

3. The most erodible soils have a high silt content,
4. Aggregates may reduce soil splash, but increase total wash losses by concentrating the surface runoff,
5. The presence of a thin sheet of surface water increased soil losses, and
6. The development of a surface crust changed soil splash and surface runoff rates.

Clods on the soil surface cause the surface water to concentrate in shallow depressions. On a cloddy surface, the effect of the surface water on soil splash will range from no effect to complete cushioning of the raindrop's impact.

1.5 Overland Flow on Upland Areas

Sediment yield and runoff from upland areas is closely related to overland flow.

1.51 Interrill Flow

On interrill areas, the surface micro-topography often has a large scale roughness such that the height of the roughness elements is greater than the depth of the flow. The interrill flow tends to concentrate into channelized flow as the water moves downslope.

1.52 Rill Development and Flow Conditions

Rills may develop anywhere on a slope because of accidental concentrations of flow. A typical rill cross-section consists of a narrow, concave channel (chute) through which the water moves with an increasing velocity until a change of slope occurs. The rill length increases as the "head-cut" moves upslope because the slope is steeper and the flow is most erosive at that point.

The effect of rainfall on the rill flow and cross-section is to (1) increase the turbulence of the runoff and its ability to transport soil particles; (2) splash soil into the rill channel from the interrill areas, thus reducing the excess transport capacity of the flow, and (3) increase the top width of the rill by wearing down the edges so the flow depth and velocity are reduced.

The transport capacity of the rill flow is further reduced by lateral inflow. Energy is lost in the turbulence produced by the mixing of the lateral inflow water with the rill flow.

The average rate of scour in a rill will decrease as the flow section is enlarged. However, the actual amount of scour at any point is dependent on the local conditions and those upslope.

1.6 Summary

Efforts to model the upland erosion process found that definitive research is needed with regard to the dynamic role of micro-topography, the effect of surface water depths on soil splash, and the effect of rainfall-induced turbulence on interrill and rill flow conditions. Maintaining soil surface roughness during row-crop production should be a major effort of any erosion control program.

Areas with a high water erosion hazard can usually be identified by observation. In general, cropland will have one or more of the following conditions:

1) long slopes,
2) rows up and down moderate or steep slopes
3) no crop residue on surface after new crop planted,
4) no cover between harvest and the establishment of a new crop canopy,
5) no filter strip of vegetation next to streams,
6) runoff from upslope pasture flowing across the cropland, and

7) poor stands or poor quality of vegetation

The selection of cropland erosion control practices is guided by estimates of the annual rates of soil movement from the field slopes. The Universal Soil Loss Equation (USLE) is the principal method of predicting annual soil losses from sheet and rill erosion by rainfall and the associated runoff on specific field areas. The Soil Conservation Service (USDA) uses the USLE exclusively for predicting soil loss.

2.0 Erosion Control Technologies

The goal of erosion control practices is to keep erosion rates within tolerances selected to preserve the productive capacity of the land. These tolerances are also acceptible for the purpose of maintaining good water quality.

Distribution of erosive rains varies significantly across the country. (Most of the year's erosion may occur from erosive rainfalls during periods of little or no soil cover). The control practices must be effective during the critical periods.

Erosion control can be accomplished by agronomic practices which are a combination of management techniques and vegetative controls.

Management techniques that aide the erosion control effort are crop residue management, seeding methods, soil treatment, tillage methods and the timing of field operations. Vegetative controls are winter cover crops, sod-based rotations, contour farming, and pernament vegetative cover. Both the management and vegetative controls fail where long slopes or large areas generating runoff exist. They must then be supported by practices such as terraces, contour strip cropping, diversions, waterways, and runoff control structures.

2.1 Description of the Erosion Control Practices

2.11 Contour Farming

The practice of planting across the slope on a line perpendicular to the slope of the land. Contour listing is essentially the same practice which loses effectiveness with post-emergence corn cultivation. Contour tillage can reduce average soil loss by 50% on moderate slopes of 2-8 percent not more then 300 feet long. Contour farming generally reduces costs of labor and machinery. This practice loses effectiveness if runoff breaks over the rows, so should be supported with terraces on long slopes. The headlands should be left in grass so no rows are planted up and downhill. There may be climatic, soil or topographic limitations to be considered. This practice can be installed at relatively low cost.

2.12 Contour Strip Cropping

A system by which ordinary farm crops are produced in relatively narrow strips of variable or even width on which close-growing meadow crops alternate with row crops. The strips are placed crosswise of the line of slope approximately on the contour. The practice was introduced by Mormons in the late 1800's when they immigrated from Germany.

Contour strip cropping reduces soil loss to about 50% of that with the same rotation when contoured only. The reduction of runoff water velocity and soil loss due primarily to slowing and filtering action of the sod strips provides the addition erosion control.

The exact width of strip needed for adequate erosion control depends on soil types, percent slope, length of slope and the crop rotation. Alternating strips of corn and spring grain will be roughly equal to contouring. This practice is often used in combination with diversions on long slopes of 400 feet or more. Contour strips are relatively low in cost to install. The farmer must keep headlands, waterways and turn strips in grass.

2.13 Terraces

Terraces are earth embankments, channels or combinations of embankments and channels constructed across the slope at suitable spacings and with acceptable grades for one or more of the following purposes:

- reduce soil erosion,
- provide maximum retention of moisture for crop use,
- remove surface runoff at a non-erosive velocity,
- improve farmability,
- reduce sediment content in runoff water,
- reduce peak runoff rates to installations downstream.

Terraces are the best mechanical erosion control practice available which allow continuous row crop production. The first complete discussion was presented by C. E. Ramser in 1914. The practice has not enjoyed widespread popularity until recently. Problems with terrace alignment resulting in point-rows, crossing the terraces with machinery and maintaining grass waterways reduced the rate of adoption. The development of a variety of outlets (waterways and underground conduits), terrace cross-sections (broadbase, steep-backslope, bench and ridgeless) and methods of construction (balanced cross section, excess fill, and excess borrow) have overcome the problems.

The design and installation of a terrace system requires skilled professionals. The construction of terraces is expensive. Adequate maintenance is mandatory to retain the terrace cross-section necessary for proper functioning of the system. Terraces may trap up to 85 percent of the sediment eroded from the field area in the channel.

2.14 Diversions

Diversions differ from terraces in that they consist of individually designed channels across a hillside. They are used to protect bottomland from hillside runoff, divert runoff away from active gullies, reduce the number of waterways, and to reduce slope length so contour strips can control erosion.

The first diversions were developed and installed in Wisconsin under the direction of O. R. Zeasman.

The principal problem causing failure is the deposition of sediment in the grass-lined channel. Maintenance is a necessity.

2.15 Grass Waterways

Grass waterways are one of the most common conservation practices known. They remove surface runoff from fields, alone or in combination with diversions or terrace systems.

A major problem in row-cropped fields is the maintenance of the grass cover. The extensive use of herbicides and their transport in surface runoff often kills the grass.

2.16 Conservation Tillage

Conservation tillage includes a variety of no-moldboard-plow systems that retain some of the residues on the surface.

1. Zero tillage, slot planting, or no-till. Plant by disturbing only the immediate area of the row. Crop residue is left on the surface for erosion control.
2. Strip tillage. Seedbed preparation is limited to a strip one-third or less of the distance between rows. A protective cover of crop residue remains on the balance. Tillage and planting are completed in the same operation.
3. Till plant. Seedbed prepared by scalping the planting area. Crop residues mixed into the soil surface between rows. Seedbed preparation and planting are done at the same time.
4. Chisel planting. Seedbed prepared by chisel plowing. Some crop residue left on the soil surface and some residue mixed in the top few inches of soil. Seedbed preparation and planting may, but need not, be accomplished in the same operation.
5. Disc planting. Seedbed prepared by discing the soil, leaving a protective cover of crop residue on the surface and some residue mixed in the top few inches of soil. Seedbed preparation and planting may, but need not, be

accomplished in the same operation.

The practices reduces spring sediment surges and reduces man, machine and fuel requirements. The development and widespread use of herbicides made conservation tillage possible. Eliminating the need to cultivate for weed control maintains the mulch and desirable clodiness on the soil surface. The soil warms at a slower rate.

The popularity of this conservation practice since its introduction in the 1950's is unparalleled. Success with conservation tillage depends on a high level of management.

Conservation tillage is most effective when tillage and planting operation are done on the contour. Contour strip-cropping and terraces may be needed in combination with conservation tillage to help control erosion.

Farmers using conservation tillage for corn production have often neglected to install the permament erosion control practices. The result is a hit-and-miss erosion control effort.

2.17 Crop Residue Management

The use of crop residues to protect land against wind and water erosion came into limited use during the 1930's. The value of a surface mulch in protecting the soil surface and slowing down runoff flow rates was quickly recognized.

A system of farming has been developed to thoroughly till the soil without necessarily inverting or burying the residue. Subsurface tillers (sweeps or rods) were devised. Chisel plows have achieved great popularity.

Seeding methods and planting equipment were developed to retain the surface mulch.

Problems have occurred. Disease, insect and weed control require careful attention.

2.18 Cover crops

The term cover crop applies to crops planted between the regular cropping periods to protect the soil. Planting cover crops is very beneficial following removal of tobacco, potato, fresh and processed vegetable crops, and corn for silage.

The crop selected should be adapted to the soil and climate, the quantity of organic material produced, easily worked into the soil, and the time of seeding. Cereal grains (rye, oats and winter wheat) are popular cover crops.

2.19 Seed-based Rotations

A good meadow reduces erosion losses to very low levels and reduces erosion rates from succeeding crops. Total soil loss is reduced but the losses are not equally distributed over the rotation.

The use of sod-based rotations can be traced to such notables as Thomas Jefferson. On many soils, crop rotations tend to favor higher yields, and insure better crop quality. A sod-based rotation is credited with maintaining the soil's physical condition and organic matter content, or in one word, tilth.

Sod-based rotations have decreased in popularity. With the major emphasis currently being placed on grain production, particularly corn, soybean and sunflower, farmers are not interested in forage crops. A corn-soybean rotation provides the most income for large numbers of cash grain farmers. The number of farmers engaged in a livestock-based agriculture has been greatly reduced. The erosion hazards and actual soil losses associated with row-crop production are accepted by farmers as the cost-of-doing-business.

2.2 Conservation Farm Planning

The conservation practices used for erosion control have been known for a long time. The fitting together of those practices is conservation farm planning.

Three years ago the Government Accounting Office (GAO) charged that the Soil Conservation Service and Agricultural Stabilization and Conservation Service spends too much time preparing technical analyses of a farm's situation and preparing detailed engineering programs. GAO thought the staff was not spending enough time in the field encouraging landowners and checking to be sure they have simple, common-sense, every-day erosion control measures installed and working.

The American farmer expects to till, plant, harvest and perform other needed operations at speeds greater than 5 mph. Prescription conservation programs must be developed to fit the management needs of the farmer. Selection of the appropriate conservation tillage technique demonstrates the need. No-till leaves most of the residue on the surface. A livestock farmer will have several questions. Should he/she protect the soil by leaving all the residue, feed some, or use the biomass to produce energy ? The recommendations should be in order, (1) left on the land if needed for maintaining productivity, and (2) remove that amount not needed for erosion control. Experts have estimated that nearly one-half of the residue could be removed from 74% of the cornbelt's acreage. Partial removal requires knowing how much residue is in the field, the amount that can be removed safely, and the technique to be used. Until the farmer has developed experience, he/she must have detailed, professional advice.

3.0 Erosion Control in the Future

The principal emerging technology for improving erosion control efforts is the use of predictive models. Researchers are currently describing the erosion processes in terms of hydraulic, hydrologic, meteorologic and other physical relationships as well as parameters describing the soil properties influencing their erodibility. The goal is to select the most efficient combination of erosion control practices needed to maintain, restore, or enhance soil productivity. The use of computors allows one to simulate the possible erosion control strategies, evaluate the results of each, and choose that which allows the greatest number of management options while protecting the land and water resource. The time needed to develop accurate predictive erosion control models will depend on several factors, but will require a minimum of 5 years. The most important factor is research support.

4.0 Recommendations

1. Eliminate the cost-sharing programs to farmers for installing erosion control practices. The public is not getting the maximum return for the dollars expended. With the currently available tax advantages, the farmers may be money ahead without cost-sharing. More importantly, cost-sharing programs do nothing to help landowners with the constant-care maintenance costs.
2. Make a significant long-term commitment to erosion control by increasing the research support. The agricultural community has the terrible feeling that the research account is overdrawn. We must make land use and erosion control decisions based on knowledge rather than guesses.
3. Successful farmers prefer to make decisions based on the best information and professional advice available. The professional staff, particularly the Soil Conservation Service technicians, Extension Agents, and Soil and Water Conservation Districts employees, is not large enough. This country must support an increase in the number of professional advisors. The farmers cannot be expected to make the correct erosion-control decisions if the advisors with time for in-depth discussions are not available.
4. The USDA-Soil Conservation Service has used land resource regions (20) and major land resource areas (156) to develop and coordinate soil and water conservation programs. Regulatory programs

necessary to meet water quality needs could be fitted to this system. Imposing soil loss limits will result in a relative redistribution of income among regions. These differential impacts can be recognized and dealt with in national policies designed to reduce soil erosion.

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Background Paper No. 22

TECHNOLOGY ISSUES IN DEVELOPING SUSTAINED AGRICULTURAL PRODUCTIVITY ON VIRGIN AND ABANDONED LANDS IN THE UNITED STATES

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ABSTRACT

This report describes some of the potential cropland and rangeland resources on lands marginal for crops or forage production. It analyzes the technology issues related to developing the potential in ways that could better sustain the land's productivity.

The emphasis is on "virgin" lands and under-utilized lands considered environmentally or economically marginal for traditional or mainstream agricultural technologies. Descriptions of these lands and how they exist in their present state are treated in the report.

Some notion of the technologies currently available for development of under-utilized lands is considered. Rates of development and levels of productivity being achieved are described in light of the economic, social, and environmental marginalities created. Various constraints to development are identified and discussed such as lack of capital, organizational arrangements, land tenure, market influences, and government policies.

Possible new technologies currently in research and development stages that may be appropriate for marginal lands are discussed in relation to the constraints that sustained use would cause in economic, social, and environmental terms.

The report describes effects of various government policies on resource use and ways these policies can be applied in the utilization of marginal lands for maximum near-term economic benefits.

I. INTRODUCTION

The purpose of this report is to describe technologies for developing sustained agricultural productivity in virgin and abandoned lands in the United States.

At the present time, numerous technologies are available that could be employed or the intensity of their employment increased on marginal lands. A look at several new technologies indicates that they would be suitable for use on marginal lands if some of the constraints associated with these lands could be moderated. Whether such constraints could be negotiated is a major issue and involves economic incentives, social values, federal policy and law. It is important for the Congress to understand the nature of the constraints because Congress, to a large extent, influences land use intensity through enactment of laws and establishment of policies.

Inasmuch as the focus of this report is on virgin and abandoned lands, referred to above as marginal lands, some definition of these terms is necessary at the outset. There exists a notion in the minds of some citizens that a large acreage of the U.S. is still unused or "virgin." This notion is entirely false. All lands have been used for some purpose in the past and are being used at present in some manner.

Some would say that we raped our virgin lands in the great western migrations in the late 19th and early 20th centuries. Others would at least agree that they were badly used. As long as the basic soil and vegetation characteristics were not destroyed, the land can continue to be productive. The western migrations and subsequent developments tested land suitability through trial-and-error according to geographical suitability (Brown 1948) using technologies available at the time. In subsequent years, new and modified technologies that were developed in the Land Grant Colleges and in State and Federal Experiment Stations have been tested against various constraints to determine whether the land could be upgraded in its utilization. A large proportion, nearly half, of the marginal lands of the west are publicly owned and managed by federal agencies (Public Land Law Review Commission 1970), primarily by the U.S. Forest Service and Bureau of Land Management. These generally are the residual rangelands not taken up in private ownership under the provisions of various land disposition laws.

The present federal policy is to manage these marginal lands for sustained production of multiple uses such as grazing, timber, wildlife, water and recreation under provisions of the multiple use acts of 1960 for the Forest Service and 1964 for the Bureau of Land Management.[1] Therefore, it is not appropriate to refer to these marginal lands as unused or virgin. However, such lands and the associated private and state lands may be considered as underutilized when viewed from the standpoint of new or improved technologies available to increase their productivity.

The term abandoned lands also deserves some discussion prior to elaboration of the technologies available to develop them. The suitability of the term "abandoned" may be questioned because of the generally high value placed on land of any productivity, present or potential. There are few abandoned lands in the U.S. except for those areas exploited for some mineral resource or used as a dumping ground for residues. Where the costs of reclamation exceed possible benefits from appropriate uses, lands have remained abandoned and continue in some cases to contribute to environmental degradation. Provisions of PL 95/87, the Surface Mine Control and Reclamation Act of 1977, call for reclamation of abandoned surface coal mined lands using royalties collected from each ton of coal mined. This law may serve as an example for ways to recover other lands abandoned after resource extraction and residual disposal.

Another type of abandoned land occurs as a result of speculative land development. Buyers not interested in productivity have allowed lands to lay idle or to produce at reduced levels because of poor management practices and unwillingness to employ long range improvement. Continued and unrestricted land speculation around the perimeters of population centers is removing significant acreages of prime agricultural land from the productive potential of the U.S. (USDA Agencies 1975). Policy changes on land use incentives as well as application of new technologies will be needed to sustain and maintain the productive potential of lands threatened by land speculation.

II. LAND RESOURCES

The land base of the United States is varied as to use potential and location. Precipitation and temperature patterns greatly influence the level of productivity and types of crops or natural vegetation (Küchler 1964) that grow in each region. Areas of low productivity such as rangeland or marginal cropland have natural climatic constraints that limit the types of crops or natural vegetation that are adapted to produce within the climatic limitations. Technological applications have and could continue to expand the list of species that could be grown in a given climatic region by providing supplemental water, increasing plant tolerance to stress, or modifying cultural practices to accelerate plant growth. Climatic limitations should not be considered inviolate even though they are sometimes formidable. Irrigation technology has in the past made possible the cultivation of areas of marginal or undependable rainfall. Lavish use of water characterizes the way irrigation has been applied to crop production in marginal areas. More effective use of limited water supplies will be necessary to sustain U.S. productivity in the future. Improved land capability and condition inventories employing remote sensing (Mitchell et al 1977) would assist in determining priority areas for development.

This report recognizes that the 2,264 million acres of the United States were considered in five major categories by the U.S. Geological Service (Anderson et al 1976) based on data provided by other federal agencies and the various states. Table 1 shows the various general uses placed on these lands. In the cropland category those lands listed as crop failure, cultivated

Table 1. Major land types and use categories, United States, 1969.

		Acres (millions)		Percent
Cropland			472	20.9
Cropland used for crops		333		
Cropland harvested	286			
Crop failure	6			
Cultivated summer fallow	41			
Soil improvement crops and idle fallowland		51		
Cropland used only for pasture		88		
Grassland Pasture and Range			604	26.7
Forest Land			723	31.9
Grazed		198		
Not grazed		528		
Special uses			178	7.9
Urban areas		35		
Transportation areas		26		
Rural parks		49		
Wildlife refuges		32		
National defense, flood control and Industrial areas		26		
State owned institutions, misc.		2		
Farmsteads, farmroads, lanes		8		
Miscellaneous land [1/]			287	12.6
TOTAL			2,264	100.0

[1/] Tundra, glaciers, ice fields, marshes, swamps, bare rock areas, beaches, barren desert.

summer fallow, lands planted to soil improvement crops and fallowland, and croplands used only for pasture may be considered marginal and will be discussed in this report. Likewise, grassland pasture, rangelands, and grazed forest lands will be discussed in terms of their location, environmental parameters, ownership, history of use and reasons why they are used as at the present.

A. Marginal Crop Lands

Approximately half of the 186 million acres of low production, high risk croplands could be considered marginal according to Table 1. These are croplands where precipitation is insufficient to consistently assure a satisfactory yield each year without employing some type of technology to augment the effectiveness or amount of natural precipitation for production of conventional crops.

These marginal or under-utilized lands are located on the dry side perimeter of climatic zones of adequate precipitation or where water is not available for regular irrigation. Some of the major locations are the great plains (Figure 1), west and south of the Palouse wheat growing region in Washington and Oregon, the Snake River Plains in Idaho, eastern Montana, the upper levels of the Great Central Valley of California, and small scattered locations in the southwestern United States. Environmentally these lands receive less than 20 inches of precipitation annually which occurs partly as snow in the winter and as rain in the growing season. Winter temperatures are cold -- often below zero but spring temperatures are favorable for plant growth. Erratic patterns of drought and high temperature create uncertainty and risks in crop production (Thornthwaite

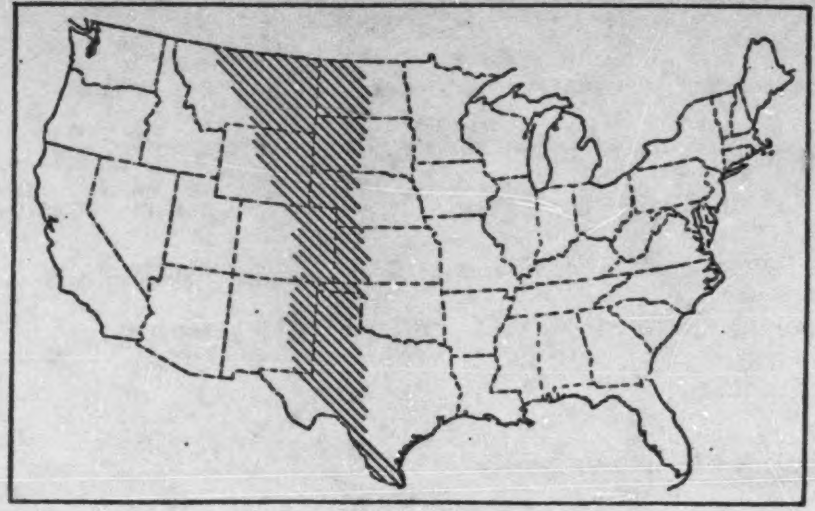

Figure 1. General location of less productive lands west of the highly productive grain belt of the U.S.

1941). All of these lands are in private ownership and have been used for crop production, primarily wheat and other small grains. The main impetus for development began after the U.S. Civil War (Brown 1948) when substantial agricultural expansion occurred partly as a result of the Homestead Act of 1862 and the Desert Land Act of 1877. The degree to which these lands are used for crop or pasture production depends to a large extent on agricultural prices and costs. When crop prices and climatic cycles are favorable, the emphasis shifts from pasture to crops. The reverse is true under unfavorable conditions. Intensive crop production during drought years is not only uneconomic but can cause soil erosion as a result of an inadequate vegetative soil cover. Obviously, the lands closer to areas of optimum climate are more stable than those on the outer fringe where risks of crop failure are greater.

B. Grassland Pasture and Range

Much of the nonforested lands west of the 100th meridian are arid and semi-arid range and pasture land (Figure 2) with the exception of intensively-farmed land under irrigation or in small valleys with favorable climate. A U.S. Forest Service rangeland assessment and environmental study (Forest Range Task Force 1972) documents the condition and animal carrying capacity of these lands which ranges from 3.2 acres to support a cow and calf for one month (one animal unit month) on prairie grassland to 8.3 acres for an animal unit month on sagebrush range. Federal ownership is predominant and ranges from 36% of the total land of Colorado to 75% of the state of Nevada. The average for the eleven western states is 49% federal ownership. Private lands adjacent to government lands provide a base of operations for ranches to graze their livestock under fee permits on the public lands.

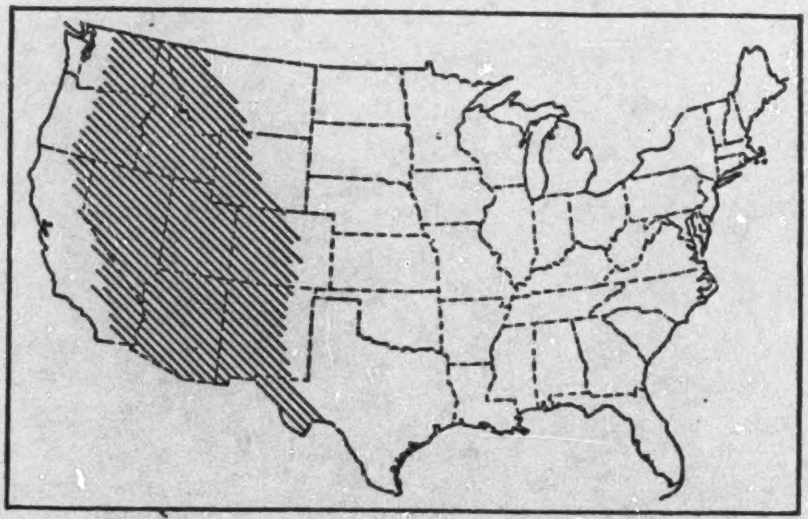

Figure 2. Generalized location of western rangelands.

All of the grassland pasture and rangeland is currently used but the intensity of use may not be at the potential in all cases because some have a downward trend in condition which requires a reduction in grazing use. In other cases, conflicting rangeland uses such as recreation or watershed protection may require that grazing use be reduced or withdrawn. Current environmental regulations are also causing a reappraisal of grazing use on certain western rangelands.

According to the Forest Range Task Force (1972) the rangeland types with the greatest potential for increased productivity under intensive management are plains grasslands, annual grasslands, and desert grasslands. The desert shrublands could be increased in productivity by approximately 35% by intensive management.

C. Grazed Forest Land

Grazed forest lands are located in most open forested areas (Figure 3)

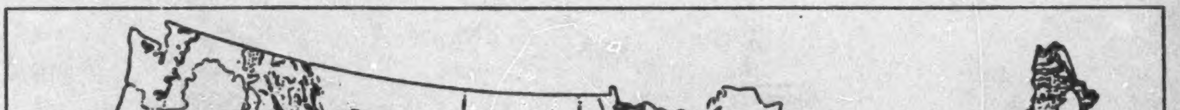
PACIFIC OCEAN
ATLANTIC OCEAN
PACIFIC FOREST
CEDAR, DOUGLAS-FIR, REDWOOD
PONDEROSA PINE
SPRUCE-FIR
WOODLAND, BRUSHLAND, AND PRAIRIE
ATLANTIC FOREST
NORTHERN HARDWOODS
OAK
SOUTHERN PINERIES
MANGROVE
SPRUCE-FIR

Figure 3. Forested regions of the U.S. Within these forested areas are lands suitable for grazing at some seasons of the year or early in the forest regeneration process.

where forest density is not high enough to preclude the growth of forage understory species. Grazeable areas generally form a mosaic with dense timber. Tree density reduction for lumber production also opens up areas for grazing during the early years of forest regeneration. Grazed forest lands are environmentally suited for both tree production and grazing but as precipitation decreases, the favorability shifts to forage production for grazing.

Most of the grazed forest lands in the West are in federal or state ownership. In contrast, private forestry companies concentrate only in the ownership of lumber producing forests. Historically, the grazed forest lands have sustained grazing since settlement of adjacent areas and as a result many acres were overgrazed. As management restrictions by federal agencies have developed the general range forage conditions of these lands has improved.

Forested lands with a potential for improved productivity for grazing are the Douglas Fir and Ponderosa Pine forests in the West and the Longleaf Slash pine and Oak-hickory forests in the East. (Forest Range Task Force 1972). The reasons why these lands are not presently used more intensively for range are that in solving multiple use conflicts, a higher value is often given to watershed, forest production or environmental quality than for grazing.

D. Abandoned Lands

The amount of land abandoned following resource extraction in the U.S. is very small in relation to the total land base. The actual acreage is difficult to determine because not all lands are legally abandoned. Without reclamation, however, the productivity is lost even though the ownership is known. According to the U.S. Bureau of Mines, the total acreage disturbed by surface and open pit mining from 1930 to 1971 was 3,687,100 (Table 2). However, appropriate reclamation practices, the period of disturbance and non-productivity can be temporary.

Some of these lands are in areas where the climatic potential is favorable for substantial crop or forage production and their usefulness should not be permanently lost. The Surface Mine Reclamation and Control Act of 1977 provides a means for the reclamation of abandoned lands and requires that all lands currently be surface mined for coal be

Table 2. Land disturbed by surface and open-pit mining 1930-1971 (U. S. Dept. of Interior,Bureau of Mines 1974).

Mineral	Acres Disturbed
Coal	1,500,000
Sand and Gravel	660,000
Stone	516,000
Misc. Commodities	480,000
Clays	167,000
Copper	166,000
Iron ore	108,000
Phosphate Rock	77,300
Uranium	12,800
Total	3,687,100

reclaimed as an ongoing operation with mining. Thus, the nation may expect to see the lands drastically disturbed in coal surface mining returned to some state of productivity. The remaining disturbed acreage should be of continuing concern.

Lands whose productivity is neglected because of a shift in ownership or accessibility brought about by speculation requires special attention. These lands are in private ownership on the margins of urban and industrial centers and their acreage is unknown. The reasons why they are not now used is because their speculative value exceeds their short term productive value even though some may be classified as prime agricultural land. Inasmuch as the management of these lands is the same as adjacent high producing lands in their general region, there is no need to discuss appropriate or new technologies but to implement land use policies at the local, state, and federal level that will encourage their continued productivity and not "abandon" them to premature and sometimes unnecessary urban (sprawl) development.

III. TECHNOLOGIES CURRENTLY AVAILABLE .

The technologies currently available for use on marginal croplands, rangelands, and drastically disturbed lands are as varied as the locations and conditions of the lands themselves. Technologies appropriate for each of the four groups of underutilized lands; marginal croplands, pasture and rangeland, grazed forest lands, and drastically disturbed lands will be discussed separately.

A. Marginal Crop Land

Levels of productivity being achieved on marginal crop lands are considerably less, on the average, than in areas of optimum production simply because of the depressing impact of climatic extremes. For example, average wheat production per acre in Kansas is 40 bu/acre as compared with 16 bu/acre in eastern Colorado.

Present technologies are extremely advanced in comparison with other regions of the world and include use of highly developed and adapted plant varieties, mechanical planting and tillage, irrigation, fertilization, pest control, mechanical harvesting, and bulk storage.

Environmental, social, and economic externalities generated by employing these technologies to expand intensive crop production into the more marginal of the rainfed crop producing lands include soil erosion, depletion of soil fertility, reduction of ground water supplies, and in some locations breaking out grazing land for risky crop production. The main social and economic changes which have occurred as a result of marginal cropland use are a gradual loss of community viability as cyclic crop failures and increased mechanization call for fewer agricultural workers. Continuation of present practices that require high energy and fertilizer inputs may not be possible in the face of increasing costs and short energy supplies.

Overdrafting of aquifers is a critical problem facing areas where irrigation water is obtained by pumping from underground reserves. Widespread reports indicate an irreversible depletion of the Ogallala aquifer which underlies parts of the high plains states from Texas to Wyoming (Walsh 1980). Without irrigation, some croplands will be returned to the original vegetation while others will be suitable for a transition to less water-intensive crops.

Even if aquifers in other regions are capable of sustaining present withdrawal rates, the increase in pumping costs caused by escalating electricity rates will sharply restrict the amount of pumping that can be budgeted within existing crop production yields. Substitution of crops with minimal water requirements can help farmers continue to produce. Greater efficiency in the application of available technologies is constrained by a "status quo" attitude, high interest costs, availability of development capital, and government policies that tend to discourage innovation.

B. Grassland Pasture and Rangeland

Technologies currently available for development of grassland pastures and rangeland are generally conventional practices related to management of grazing animals at appropriate times and intensities to avoid overuse. Technologies for grazing resource development consist of a wide range of practices depending on the favorability of the land unit -- with pasture lands having the highest favorability and arid rangelands the least. Practices include control of undesirable plants, seeding of improved forage species, soil fertilization where rainfall is adequate, irrigation of pastures where water is physically and economically available, and appropriate control of weeds and insects (Valentine 1971). At present, these technologies are finding limited application on public rangelands because of other resource use parameters. Level of livestock productivity have not increased in recent years (Forest Range Task Force (1972)) but have declined on rangelands due to cuts in grazing permit numbers because of environmental conflicts.

Environmental externalities are generally low on the grassland pasture and high on poorly managed rangeland. Where land use is practiced in excess of the inherent capacity to function, the following externalities increase in severity: soil erosion from wind and water influences, vegetation composition change associated with declining range condition, and pollution of stream flow (Council on Environmental Quality 1979). Other uses possible under a multiple use concept on rangelands also may be reduced in potential. However, rangeland under good management and in good condition does not display the environmental problems listed above.

Economic and social impacts in areas devoted primarily to grazing of livestock stem from changing economies of scale. Larger farm and ranch units appear to be necessary to support increased capital costs and finance improved technologies of land development. Decreased productivity, migration of rural people to urban areas, and demise of rural community vaibility result when land productivity falters.

On some public rangelands managed by federal agencies, competition from uses other than grazing is causing a reappraisal of the number of animals that can graze an area. Numerous Environmental Impact Statements (U.S. Department of Interior 1980, 1979) call for some reductions in livestock numbers while at the same time, these studies identify areas that require the application of specific improvement practices to increase livestock carrying capacity and improve the range for other uses on a sustained basis.

Two major constraints limiting the implementation of current practices are shortage of capital and government policy. In the public sector, commitment of BLM funds to preparation of EIS's and other ongoing programs leaves little latitude for funding development (range improvement) projects. Passage of legislation (the Rangelands Improvement Act of 1978) designed to improve rangeland conditions has not helped because funding did not accompany the legislation. Thus, federal policies for environmental quality have not helped to improve rangeland forage production significantly. Observations have shown that simply protecting from use has not brought about significant improvement.

In the private sector limited availability of development capital and high interest costs have deterred pasture and rangeland development. Relatively low livestock prices have also depressed incentives for forage development. A revolving loan fund for rangeland development authorized by the Utah State Legislature is an example of a strategy for financing high priority projects on private land. Other western states may follow this example to stimulate rangeland improvements.

C. Grazed Forest Land

Grazed forest lands are generally lands of high potential for grazing use but because of their value for forest production -- even at a lower level than typical timber forests, they are underutilized for forage production. All lands may be considered as developed to some degree at present but according to the Forest Range Task Force (1972) a management emphasis on forage production could bring moderate increases in livestock use. Child and Byington (1979) emphasized that application of current range improvement technologies plus a commitment to livestock production for a temporary period following wood harvest could significantly increase the net return from southern pine forests. Because of the value forests have as watersheds, care must be exercised in forest-range watershed management to avoid erosion problems.

D. Abandoned Lands

Suitability of current technologies available for development of abandoned lands depends on the nature of location of the lands. Land used for residue tailings and spoil disposal may not be suitable for development without extensive coverage with a percolation barrier or chemical amendment followed by coverage with sub and surface soil. In some cases, extensive research is needed to provide an appropriate technology to deal with toxic properties of tailings and residues.

In surface mine reclamation, the current technologies are spelled out in reports and regulations (Imhoff et al 1976, Office of Surface Mining 1979, Shaller and Sutton 1978). Although standard practices consist of regrading spoil to approximate original contour, replacement of topsoil, seeding native species, and adding mulch and fertilizer as necessary, precautions against erosion and off-site runoff are mandatory. In actual practice, modifications are necessary to meet regional conditions such as aridity and salinity in the West as compared with abundant rainfall and acid conditions in the East.

Obtaining sustained productivity without environmental degradation is as necessary as meeting the requirements of premining or approved post mining land use. Numerous alternative post mining land uses are theoretically possible, but grazing in the west and crop production in the midwest are prime important post mining land uses.

The most important constraints to land reclamation are costs of reclamation practices, need for more site-specific technical information, and flexibility in reaching the postmining land-use goals.

Lands temporarily neglected because of untimely or uncoordinated real estate speculation require only stronger incentives or regulatory pressure to remain productive. Technologies appropriate for adjacent lands should also be appropriate for the unused land.

IV. NEW TECHNOLOGIES AVAILABLE

A number of new technologies are in various stages of availability for developing marginal, underutilized or abandoned lands. Some may be more appropriate for certain areas of the country than others because of plant adaptation, land suitability, and competing uses for land resources. Table 3 provides an overview of possible new technologies.

A. New Crops

Almost all of the major crops grown in the United States are imports from the eastern hemisphere. Some notable exceptions are lima beans, corn, and tobacco. However, many species native to the western hemisphere hold great promise for future production. One of the main virtues of native plants is that they are already adapted to numerous habitats that may be available for consideration in new crop areas. The kinds of new crops available for intensive development range from those valued for special products such as latex from guayule (*Parthenium argentatum*) to those useful for a food product such as edible seeds from the desert buffalo gourd (*Cucurbita foetidissima*).

A detailed discussion of 12 new agricultural crop plants was edited by Ritchie (1979). Thiesen *et al* (1978) prepared a report to the National Science Foundation on the feasibility of introducing food crops better adapted to environmental stress. Their list, containing 54 species, describes many species indigenous to the United States that could better utilize areas of marginal cropland, pasture, and even arid rangeland sites than existing vegetation. A reproduction of a summary table developed by Thiesen *et al* (1978) provides important information on the longevity, principal product, similar products, adaptation, land requirements, and cultural practices

Table 3. Some examples of technologies available for development of marginal and abandoned lands.

	Stage of Development
A. New Crops	
Some major ones of high potential are:	
jojoba buffalo gourd milkweed	Depends on species
guayule oil seed crops rabbitbrush	Depends on species
B. Water Management Practices	
Spaced planting	Operational
Water harvesting	Pilot
Drip Irrigation	Market development
Surface treatments to retard water loss	Research
C. Production of Energy Crops	
Use existing biomass on rangeland	Research
New crops: a. shrubs b. milkweed	Research
D. Genetic Engineering, Tissue Culture	
Tissue culture propagation of unique genotypes	Market development
Bioengineering, incorporation of desirable genetic traits	Research
E. Soil Fertility Augmentation, Plant Adjustment	
Nitrogen fixation by plants	Research
Mycorrhizal inoculation	Pilot
F. Range Improvements and Livestock Management	
Grazing management to effect greater forage use	Pilot
New animal species and combinations of conventional species	Research and Operational
Seeding of improved forage species	Operational

required to produce the crop (Table 4). Some of the crops such as guayule and jojoba are already under pilot scale development.

Each of these potentially useful crops requires specific research and development information and experience to determine its actual worth. The opportunity that any of these crops might have to replace a present crop or find a new niche in an underutilized land area appears high, especially those plants that would have a low energy requirement and could thrive on minimal water, low maintenance, and harsh conditions.

Anticipated environmental problems center around resistance to "convert" existing marginal cropland or rangeland areas to extensive agriculture. Economic hardship would consist of providing advance funding for new crop development as well as the risks involved in working with unknown crop attributes. Unless/until large scale development occurs, only minor social impacts would be expected. On the positive side, any successful development of a profitable new crop could be of benefit in reversing an out-migration trend in marginal/low producing agricultural areas.

The main constraints to development are capital development costs, inadequate basic and applied research information, time, markets, and a general reluctance to invest time or money in the unknown.

B. Improving Water Use Efficiency

One of the most critical challenges in producing crops or livestock forage in arid and semi-arid regions is finding ways to increase the efficiency of water use. Pierre et al (1966) edited a series of papers dealing with the occurrence of moisture in plant soil systems and ways to increase

Table 4. Summary Information on 54 Potential New Crops

Crop	Life Span	Part Used	Product	Market Competition	Adaptation	Land Use Competition	Cultural Operations	Potential Magnitude & Significance	Needed Work
Hydrophytes:									
* Cattail	Perennial	Rhizome	Starchy Staple	Sweet Potato	Wet	Swamp	Hand Labor	Small	Agronomic Processing Machinery
* Chinese Waterchestnut	Perennial	Tuber	Starchy Staple	—	Wet	Swamp	Hand Labor	Small	Agronomic Processing
Stokesia	Perennial	Seed	Industrial Oil	Synthetic Epoxy	Wet	Bog	Mechanized	Medium	Agronomic
* Wild Rice	Annual	Seed	Grain	Rice	Wet	Lake	Hand Labor	Medium	Agronomic
Mesophytes:									
American Elderberry	Perennial	Fruit	Fruit	Small Fruits	Fertile	Idle Pasture	Hand Labor	Small	Agronomic
American Persimmon	Perennial	Fruit	Fruit	Plum	Infertile	Idle Pasture	Hand Labor	Small	Agronomic Handling
Bambara Groundnut	Annual	Seed	Nut	Peanut	Infertile	Sorghum	Mechanized	Small	Agronomic
* Black Walnut	Perennial	Seed	Nut	Pecan English Walnut	Fertile	Forest	Hand Labor	Medium	Agronomic
* Broad Bean	Annual	Seed	Bean	Dried Beans	Heavy Soils	Peas, Hay	Mechanized	Medium	Agronomic Demand
* Chinese Chestnut	Perennial	Seed	Nut	Nuts	Infertile	Forest	Hand Labor	Small	Agronomic
Cold Hardy Citrus	Perennial	Fruit	Fruit	Citrus	Cold	Pasture	Hand Labor	Small	Agronomic Processing
* Crambe	Annual	Seed	Industrial Oil	Rape Seed	Cold	Wheat Corn	Mechanized	Large	Agronomic
Crotalaria	Annual	Bark/ Stem	Fiber	Wood Pulp	Infertile	Peanuts	Mechanized	Small	Agronomic Processing
Finger Millet	Annual	Seed	Grain	Rice	Infertile	Peanuts	Mechanized	Small	Agronomic Demand
* Grain Amaranth	Annual	Seed	Grain/ Vegetable	Wheat Germ. Spinach	Cold, Infertile	Wheat	Mechanized	Medium	Agronomic Demand
Guar	Annual	Fruit/ Seed	Green Beans	Other Beans	Infertile	Sorghum	Mechanized	Small	Agronomic
Hemp	Annual	Plant/ Seed	Fiber, oil drugs	Wood Pulp	Fertile	Corn	Mechanized	Small	Agronomic
* Kenaf	Annual	Bark/ Stem	Fiber	Wood pulp	Fertile	Peanuts	Mechanized	Large	Harvest, Processing

Table 4. Summary Information on 54 Potential New Crops (cont.)

Crop	Life Span	Part Used	Product	Market Competition	Adaptation	Land Use Competition	Cultural Operations	Potential Magnitude & Significance	Needed Work
Mesophytes (cont.):									
Lablab Bean	Annual	Seed	Bean	Other Beans	Infertile	Peanuts	Mechanized	Small	Agronomic, Demand Processing
Lambs-quarter	Annual	Seed/ Plant	Grain/ Vegetable	Wheat germ Spinach	Dry, wet Infertile	Wheat	Mechanized Hand Labor	Small	Agronomic Machinery Processing Demand
* Limnanthes	Annual	Seed	Industrial Oil	Sperm whale oil	Fertile	Wheat	Mechanized	Medium	Agronomic Processing Machinery
Litchi	Perennial	Fruit	Fruit	Small Fruits	Fertile	Pasture	Hand Labor	Small	Agronomic
Longan	Perennial	Fruit	Fruit	Small Fruits	Warm Fertile	Pasture	Hand Labor	Small	Agronomic Machinery
Loquat	Perennial	Fruit	Fruit	Small Fruits	Warm Fertile	Pasture	Hand Labor	Small	Agronomic Machinery
Mayhaws	Perennial	Fruit	Fruit	Small Fruits	Dry, wet	Forest	Hand Labor	Small	Agronomic Demand Machinery
Melon Pear	Annual/ Perennial	Fruit	Fruit	Citrus Peach	Warm	Vegetable	Hand Labor	Small	Agronomic Demand Processing
Mexican Yam Bean	Perennial	Tuber	Starchy Staple	Potato	Dry	Sorghum	Mechanized	Small	Agronomic
Moth Bean	Annual	Seed	Bean	Other Beans	Dry Infertile	Peanut	Mechanized	Small	Agronomic
Naked Seeded Pumpkin	Annual	Seed/ Fruit	Nut, Vegetable	Sunflower seed	Fertile	Soybean	Mechanized	Small	Agronomic Processing
Oriental Persimmon	Perennial	Fruit	Fruit	Plum	Infertile	Idle Pasture	Hand Labor	Small	Agronomic Handling Demand
Pokeberry	Perennial	Young plant	Vegetable	Spinach	Infertile	Idle Pasture	Hand Labor	Small	Agronomic Demand Processing
* Pummelo	Perennial	Fruit	Fruit	Citrus	Fertile	Vegetable	Hand Labor	Small	Agronomic Demand Processing
* Quinoa	Annual	Seed/ Leaves	Grain Vegetable	Wheat germ Spinach	Infertile	Wheat	Mechanized	Small	Agronomic Demand Processing
Rice Bean	Annual	Seed	Bean	Other Beans	Dry	Peanuts	Mechanized	Small	Agronomic
Service Berry	Perennial	Fruit	Fruit	Small Fruits	Infertile	Idle Pasture	Mechanized	Small	Agronomic Processing

Table 4. Summary Information on 54 Potential New Crops (cont.)

Crop	Life Span	Part Used	Product	Market Competition	Adaptation	Land Use Competition	Cultural Operations	Potential Magnitude & Significance	Needed Work
Mesophytes (cont.):									
* Shagbark Hickory	Perennial	Seed	Nut	Nuts	Infertile	Forest	Hand Labor	Medium	Agronomic Machinery
Xerophytes:									
Buffalo Berry	Perennial	Fruit	Fruit	Small Fruit	Dry	Range	Hand Labor	Small	Agronomic Machinery
* Buffalo Gourd	Perennial	Seed	Protein & Edible oil	Soybean	Dry	Desert	Mechanized	Large	Agronomic Machinery
Bush Cherry	Perennial	Fruit	Fruit	Cherry	Dry, Infertile	Idle Pasture	Mechanized	Small	Small
Foxtail Millet	Annual	Seed	Grain	Rices	Dry	Sorghum, Range	Mechanized	Small	Agronomic Machinery
* Guayule	Perennial	Stem, Root	Latex	Synthetic Rubber	Dry	Cotton	Mechanized	Large	Agronomic
* Jojoba	Perennial	Seed	Industrial Oil	Sperm-whale oil	Dry, infertile	Desert	Hand Labor	Large	Agronomic Machinery
Lesquerella	Annual/ Perennial	Seed	Industrial Oil	Caster Oil	Dry	Sorghum	Mechanized	Small	Agronomic Processing
Metcalf's Bean	Perennial	Seed	Grain	Other Beans	Dry	Range	Hand Labor	Small	Agronomic Machinery
* Mung Bean	Annual	Seed	Vegetable	Other Beans	Dry	Sorghum	Mechanized	Medium	Agronomic
Olneya Bean	Perennial	Fruit, Seed	Nut, Bean	Peanut	Dry	Desert	Hand Labor	Small	Agronomic Demand
Pearl Millet	Annual	Seed	Grain	Rice	Dry Infertile	Sorghum, Range	Mechanized	Small	Agronomic
* Pigeon Pea	Perennial/ Annual	Seed	Bean	Cowpea	Dry Infertile	Peanuts	Mechanized	Small	Agronomic Demand
* Pinyon Pine	Perennial	Seed	Nut	Nuts	Dry	Forest	Hand Labor	Medium	Agronomic Machinery
Proso Millet	Annual	Seed	Grain	Rice	Dry	Sorghum	Mechanized	Small	Agronomic
Sesame	Annual	Seed	Edible Oil	Soybean	Dry Infertile	Cotton	Mechanized	Small	Agronomic Processing
Spearscale	Annual	Seed Leaves	Grain Vegetable	Wheat germ Spinach	Dry, wet	Range	Mechanized Hand Labor	Small	Agronomic
* Tepary Bean	Annual	Seed	Bean	Other Beans	Dry Infertile	Range	Mechanized	Small	Agronomic Demand
Western Sandcherry	Perennial	Fruit	Fruit	Cherry	Dry, cold	Idle Pasture	Mechanized	Small	Agronomic Demand

water use efficiency through soil and crop management practices. Although prepared fifteen years ago, the various innovative practices recommended remain unimplemented. Not all moisture use efficiency practices are suitable for each crop or forage producing situation but those that are must be adapted to meet specific site conditions. Only a brief overview of some possible applications is possible in this assessment.

1. Water harvesting - Stated simply, water harvesting involves the collection of runoff from a surface and directing it to an area where plants are to be grown. The practice was anciently used in the Negev desert and other locations by communities to store water and irrigate crops (Evenari *et al* 1971). Recent research at the University of Arizona and other southwest institutions suggest how water harvesting can be effectively accomplished by using surface films and other treatments to increase runoff but maintain soil surface stability (Frasier 1975, Meyers 1967). Malek (1980) evaluated several surface stabilizing materials to increase surface runoff for use in establishing vegetation as a disturbed land rehabilitation measure in arid regions where irrigation water would not be available for plant establishment.

Utilization of water harvesting practices could bring many acres of otherwise productive arid soil into beneficial use. Alternate strips of land could produce crops using water harvested from adjacent surface-treated ridges or slopes. Water harvesting could also be used in the rehabilitation of land from which vital energy resources have been recovered.

2. Drip Irrigation - A drip irrigation system involves the use of drip or limited-flow emitters at spaced intervals along a water pipeline to irrigate small areas rather than trying to obtain uniform coverage with

sprinkler heads. Each spot irrigated obviously is the area planted to a crop, bush, or tree crop (Bengson 1975). The system allows for a considerable saving in the amount of irrigation water applied and could be used where arid or semi-arid land is available, but irrigation water is in limited supply. Bengson suggests using drip irrigation for land reclamation in arid regions.

3. Surface Treatments to Retard Water Loss - Numerous applications of surface treatments may be used to increase the effective use of water (Bertrand 1966). Tillage of weeds, land forming to increase infiltration in deep furrows, chemical fallow (use of a short duration herbicide to restrict water withdrawal by competing vegetation), application of a mulch to restrict evaporative loss of moisture from the soil surface, and spaced plantings of crop or forage plants can be employed to better utilize arid and semi-arid lands than at present.

C. Production Energy Crops

Numerous possibilities exist for producing crops for energy production from the extensive marginal crop and rangeland areas of the country. Utilization of these lands for new energy sources would be a means of avoiding competition with existing crops for fertilizer, water, and prime land. Some biomass crops proposed for energy production may in fact be well adapted to the relatively dry conditions of the marginal crop and rangeland areas.

1. Use of Existing Rangeland Shrubs for Biomass - Millions of acres of western rangeland currently support medium to dense stands of woody vegetation ranging in size from less than one meter high for saltbush and sagebrush to over 10 meters high for pinyon-juniper woodlands. A common range improvement

practice has been to mechanically clear these lands with bulldozers and heavy chains in order to establish forage species (Valentine 1971). If the plant material from such range improvement projects could be collected for use in energy development rather than left to decompose on the ground, approximately seven to nine tone of shrub biomass per acre would be available from over 90 million acres of sagebrush lands alone. Higher biomass volumes could be available from the 42 million acres of pinyon juniper woodlands (Forest Range Task Force 1972).

2. New Crops - Planting of selected shrub species for biomass energy may provide another means of optimizing rangeland productivity. Van Epps *et al* (1981) have shown a potential of from 20,000 to 97,000 Kg/ha of biomass if spaced plantings of genetically large shrubs were planted in densities equal to those found in favorable field locations. The energy yield potential could range from 44 million Kcal/ha using fourwing saltbush (*Atriplex canescens*) to 458 million Kcal/ha for greasewood (*Sarcobatus vermiculatus*).

Another crop possibility for marginal lands is milkweed (*Asclepias* spp.), a common agricultural weed of moderately saline soils. Buchanan *et al* (1976) ranked milkweed among nine species out of 100 as having a high potential for development as a new crop. A pilot scale study of this plant by Plant Resources Institute of Salt Lake City, Utah, indicated that equivalent crude oil yields of approximately 200 gallons/acre plus 300 gallons of ethanol, 500 gallons of methanol and other residual products could be harvested annually from field plantings of milkweed (Halliday 1980).

D. Tissue Culture and Bioengineering

1. Tissue Culture - A problem with utilization of crops plants with unique features, or native plants that have a high potential for development,

is the time required to breed genetically stable agricultural varieties. Vegetative propagation by means of tissue culture provides a means for rapid multiplication of the exact genotype desired without waiting for time-consuming normal plant breeding processes. Because only a small amount of asexual tissue (stem, buds, root, etc) is grown on a sterile, nutrient-enriched, hormonally-balanced growth medium in a controlled environment laboratory chamber, a large number of identical plants (clones) can be produced at a given time. By geometric progression the potential for duplication is enormous. Plants of high value such as selected ecotypes, rare and endangered species, unique native species, and single plant introductions from foreign sources, are the most likely candidates for tissue culture propagation.

Tissue culture technology provides a means for placing valuable plant attributes into use within a short period of time while more conventional plant breeding techniques can be followed to combine desired characteristics into one or more agricultural varieties. Some examples of crop species that have been successfully propagated by tissue culture methods include asparagus, citrus, pineapple, native shrubs for land reclamation, conifers for timber production, jojoba, and various tree species.

2. Bio-Engineering - Recent advances in basic genetic research indicate the possibility of introducing a minute amount of recombinent DNA representing a valuable physical or physiological characteristic into another organism which would thus be improved by the new characteristic. Techniques of this highly technical procedure are just beginning to be worked out for practical applications (Business Week Aug. 1980). The potential for this bio technology appears to be great and should be considered for use when a sufficiently serious problem occurs or where the potential for marginal land development is identified.

E. Soil Fertility Augmentation, Plant Adjustment

Soil nutrient deficiency is a common problem of all crop lands. Nitrogen deficiency is perhaps the most common problem because nitrate (NO_3) is easily lost from the root zone by downward leaching following a rainfall or snowmelt. Other elements may also be lost or tied up in the soil and made less available to crop or forage species. Three approaches may be considered in solving the fertility problem: (1) add necessary amounts of fertilizer to offset the observed deficiencies, (2) grow nitrogen fixing legume plants that are capable of naturally providing additional N fertilizer and (3) ensure that plants are inoculated with appropriate mycorrhizal strains to assist plants to function in low P and N status soils. Because soil fertilization is a well-known routine practice, it does not need to be discussed here but the newer practices do require some elaboration.

1. Grow Nitrogen-Fixing Plants - Common agricultural wisdom recommends the use of nitrogen-fixing plants of the legume family. Recent work is now expanding the list of nitrogen-fixing plants to include non-legumes. These newly discovered plants should be used, along with appropriate crop and forest legume species, where soil nitrogen deficiency must be overcome to obtain satisfactory crop yields. Extra effort is particularly needed to search for and develop plant species suitable for nitrogen fixation on Western rangelands. Many legume shrub species are found in African rangelands, but few if any appear to be suited for the arid regions of the United States. Recent research on nitrogen fixation in tropical grasses at the University of Florida (Schank 1980) indicate that a modest increase in the amount of soil nitrogen can be expected from growing certain grass species inoculated

with a bacterium. The potential for application of this phenomenon appears to be highly favorable and could amount to about 20% of the nitrogen budget required by forage grasses.

2. Mycorrhizae - Up until the past few years, the general understanding of the occurrence and role of mycorrhizae, a root infecting fungus, was limited to forest tree relationships. Recent work points to a very important function of mycorrhizae in the enhancement of water uptake under conditions of limited soil moisture and an increase in the uptake of phosphorus (Aldon 1978, Reeves et al 1979). These attributes of mycorrhizae are especially useful on sterile mine spoils where revegetation is desired. Whereas the mycorrhizae may be present in adequate quantity in agricultural forest and range soils, their absence in the geologic spoils exposed in the process of surface mining makes necessary the inoculation of plants or the soil in which they are grown with appropriate strains of mycorrhizae. The experimental results have been highly favorable and point out that mycorrhizal inoculation will be a standard recommendation in future land reclamation operations.

F. Range Improvements and Livestock Management

Range productivity could be increased by implementing intensive management and improvement practices (Forest Range Task Force 1972). According to this 1972 comprehensive assessment, the opportunities for increased livestock production range from 27% in the low productivity desert shrub vegetation type to 120% in the high potential prairie grasslands (Table 5). Selected sites within each of the range types could be managed for considerably greater production increases. All of the range improvement practices are presently available but few are implemented because of budgetary limitations and federal policies. Beyond the presently available range improvement practices, new possibilities are being developed. Two examples are described below.

1. Planted Shrub-Grass Pastures

Over 1 million acres of western rangeland, predominantly the sagebrush and pinyon-juniper types, have been cleared of a low-value shrub-dominated plant cover and seeded with crested wheatgrass (*Agropyron cristatum*) or other closely related species. These grasses are excellent for spring and early summer grazing but are of low nutritional value for fall livestock use. Research underway at Utah State University's Nephi Field Station shows that interplantings of fourwing saltbush and other desirable shrubs in the wheatgrass pastures can provide the necessary protein and carotene needed by livestock that the pure grass pastures lack when used for fall grazing (Otsyina *et al* 1980). Renovating the extensive range plantings of wheatgrass could provide up to two months of extra grazing for users of the western ranges at a critical time for feed availability.

2. Grazing Management Schemes - Numerous methods for improving the overall effectiveness of livestock use on pastures and rangelands have been developed in the past. The general objectives have been to obtain optimum and equal utilization of forage plants that are varied in their palatability and stages of development. To leave a substantial portion of plants unused in order to prevent serious overuse of other species often constitutes a waste of the forage resource. One of the more innovative suggestions for obtaining optimum utilization of a mixed species vegetation is to graze animals at a high intensity for a short duration (Goodloe 1969, Leithead 1974). This method reduces the selectivity that normally occurs when a small number of animals rove about

picking just the most palatable plants. Adaptations of this concept to specific range conditions could increase the utilization of mixed stands of range forage.

Table 5. Average animal unit month production of rangeland types in 1970 and potential production under intensive management.[1]

Range Type	Possible Under Intensive Mgmt[2]	Average Production in 1970	Percent Increase
Western Range			
Sagebrush	.28	.12	42
Desert Shrub	.11	.03	27
So West Shrub Steppe	.17	.06	35
Chaparral Mtn Shrub	.21	.07	33
Pinyon-Juniper	.14	.05	35
Mtn. grasslands	.33	.29	87
Mtn. Meadows	2.50	1.14	45
Desert grassland	.25	.19	76
Annual grassland	1.52	1.05	69
Alpine	.20	.21	1.05
Great Plains			
Plains Grass	.35	.31	88
Prairie	.84	1.01	1.20

[1] Data taken from p. 133 report of Forest Range Task Force (1972).

[2] Intensive management practices include fencing, water spreading, brush control, soil surface treatments, prescribed burning, seeding, fertilization pest control and selective timber-thinning.

V. GOVERNMENT POLICIES

Government policies are far more influential on the implementation of innovative technologies for exploitation of marginal lands than sale of goods and services. This is especially true in the western states which have a high proportion of federal ownership.

Environmental, research, and marketing policies are the most influential on new technology development. Environmental laws, regulations, and policies emphasize maintaining the status quo and in preserving things as they are. Thus, any suggestion for development that would involve a change in use of a land area would come under a requirement for considerable advance data on the proposed use before any action could be taken. Chances for tradeoffs or benefits from alternative courses of action are thus diminished because of the costs to determine the impacts of such actions. Only large corporations can support the extensive advance costs often required.

Preliminary research information is consistently needed prior to substantial implementation of a technology. Funding for research from the public sector is inadequate to provide the necessary information base. More funding from the private sector is a partial answer to this problem.

Marketing policies are too restrictive for new products and their utilization. Protection of existing products and applications needs to be balanced with opportunities for new materials.

A. Policies Affecting the Rate at Which Development of Marginal Lands Occurs

The most important policies affecting marginal lands development are environmental restrictions of public land use and subsidies for competing and traditional agricultural products. Any change in public land use in the is an especially sensitive issue because it may appear as a threat to environmental quality, to water use, or to existing land values. Funding policies for research also influence the rate of development. Many innovative ideas for improved practices are left without support because research funds are not only restricted in their availability, but because of the routine way they are administered through USDA and the State Agricultural Experiment stations. New ideas are isolated from funding sources except through the traditional routes prescribed by USDA where they must compete with internal vested interests and priorities established by people who may not be sufficiently aware of resource opportunities and recent developments in science.

B. Policies Affecting the Rate at Which New Technologies are Developed and Tested

The rate of technology development and testing is severely constrained by government policy. Inasmuch as the testing and development of a technology follows research, there is little to test if a research program is not productive or if restrictive public land use policies discourage development. A good example is the present lack of viable programs in rangeland improvement. Available technologies are not being used because major funding is being devoted to preparing environmental impact statements. Range improvement needs identified in these statements should receive a high priority for implementation but the agency (BLM) must continue preparation of additional EIS's. Rangeland users except these identified range improvement needs will be met, as committed in the environmental analyses.

C. Policies Affecting the Extent to Which the Development of Conservation Technologies Occurs

The tilt in government policies toward conservation as contrasted with development and maximization of near-term economic returns is evident in the large emphasis on environmental legislation in the 1970's. Some may say that the current emphasis on conservation was long overdue while others may say that only a better balance was needed. However, the best policy may be one of continuously examining national land and plant resources to develop the appropriate products and uses that are needed at the present while protecting the capability of the land to produce them in the future.

Specific policies that emphasize conservation over maximum short-term resource development are to be found in the National Environmental Policy Act, the Wilderness Act, the Rare and Endangered Species Act, the Roadless Area Review Evaluation Act, the Clean Air Act, and the Amendments to the Clean Water Act, just to name a few of the most obvious. However, each of these laws provide an important function in protecting environmental quality on a long term basis and should not be unduly criticized because they seek to correct some general harms to the nation's resources. The important point is simply that a better balance in marginal land development may provide an opportunity to achieve resource use while at the same time protecting important environmental and resource values.

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Background Paper No. 23

THE EFFECTS OF LONG TERM FERTILIZER USE ON SOIL PRODUCTIVITY

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INTRODUCTION

The United States of America possesses the most productive agricultural industry to be found any where in the world. This productivity is the result of a combination of favorable climate, productive soils and highly technical management skills. These resources combine to make the United States the principle supplier of food and fiber to world trade. Agriculture today is a highly technical industry based on management systems which require vast amounts of inputs, one of which is chemical fertilizer. In recent years agriculture has come under fire from some quarters because of its use of chemical fertilizers. Concerns have been expressed over the potential of decreased soil productivity resulting from fertilizer use, and detrimental effects on the environment, particularly water quality. This paper will attempt to address some of these concerns, as it examines the data available on long-term fertilizer effects on soils, specifically those affecting soil productivity.

The intent of this paper is to present some basic concepts of the role fertilizers play in agriculture today, the fate of fertilizer in soil and what residual effects fertilizers may have on soils and soil productivity. In doing this, key experiments and basic information available in the literature will be presented which addresses the question of long-term changes in soil productivity resulting from fertilizer use. An attempt to evaluate the data available from the standpoint of its suitability or capability of providing the needed answers will also be made.

This paper will address all of the points suggested in the Contractors Task Statement, however the organization will differ slightly. This will hopefully help the reader to make his own evaluation of the data base of long-term experiments with the help of some of the basic information provided first.

The underlying theme of this paper is to present the basic scientific principles of soil science necessary for evaluating the impact of fertilizers on soil productivity, and some of the evidence from which these principles were generated. Where appropriate, key references will be cited which will facilitate additional study by those readers so inclined.

It is not the purpose of this paper to test every conceivable hypothesis regarding fertilizer impacts on the productivity of soils, but rather to present concepts pertinent to the subject and to describe and hopefully evaluate the data presently available which is pertinent to the problem at hand.

SOME BASIC CONCEPTS

Mineral Nutrition and its Impact on Soil Productivity

Brady (1) defines soil productivity as "the capacity of a soil for producing a specified plant or sequence of plants under a specified system of management. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields". In addition to yield, quality both from a nutritional and market acceptance standpoint should be considered. For the purposes of this paper the definition of productivity will be further expanded to include the production of environmental services particularly, quality water.

A number of factors contribute to the productivity of soil. Among these are light, water, temperature, gaseous composition of the air and the availability of essential mineral nutrients. The ability of a soil to provide the essential mineral nutrients to crops is referred to as the fertility of a soil. Soil fertility has a major impact on soil productivity within a specific climatic region and is the component of soil productivity effected directly by the use of chemical fertilizers.

There are thirteen mineral nutrients known to be essential for plant growth. They are commonly divided into three groups: primary, secondary and micronutrients:

Primary Nutrients

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Secondary Nutrients

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Micronutrients

- Boron (B)
- Chlorine (Cl)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Zinc (Zn)

They are classified basically on the relative amounts taken up and utilized by plants. The primary nutrients, N, P and K are used in relatively large amounts and are usually the first to become deficient in a soil. They also represent the principal nutrients added as fertilizers. The secondary and micronutrients are found deficient in soils less frequently and are normally utilized by plants in much smaller amounts.

They are just as essential for adequate plant growth, however. In the production of agricultural crops the essential mineral nutrients must be supplied in a form available for plant uptake, in adequate quantities, at the time needed. If the soil cannot supply nutrients from native reserves then they must be supplemented from some other source. Generally this supplementation is as a fertilizer, or as an animal waste or crop residue.

The amounts of some of the essential mineral nutrients taken up by the above ground portions of selected crops and the amounts removed from the soil in the harvested portions of those crops are listed in Table 1. While the amounts removed will vary considerably, these figures provide some feeling of the amount of plant nutrients removed through crop production.

Unfortunately, the native fertility of most U.S. soils has not proven adequate to provide the nutrients needed to support the level of productivity required to meet world demand. Thus significant quantities of animal and municiple wastes, crop residues and chemical fertilizers are used to enhance the soils ability to supply the nutrients required for crop production.

Fertilizer use in the U.S.

A number of organizations collect and summarize information on U.S. and world fertilizer use. The National Fertilizer Development Center, a part of the Tennessee Valley Authority and the USDA both publish such summary statistics. Some interesting and important information on fertilizer use can be found in these statistics.

Table 1. Approximate utilization of nutrients by selected crops. From: Tisdale and Nelson (2).

Crop	Yield per Acre	Nitrogen (lb)	P_2O_5 (lb)	K_2O (lb)	Mg (lb)	S (lb)
Corn (grain)	180 bu	170	70	48	16	14
(stover)	8000 lb	70	30	192	34	16
Soybeans (grain)	60 bu	252	49	87	17	12
(straw)	7000 bu	84	16	58	10	13
Wheat (grain)	80 bu	144	44	27	12	5
(straw)	6000 lb	42	10	135	12	15
Alfalfa (hay)	8 tons	450	80	480	40	40
Orchard Grass (hay)	6 tons	300	100	375	25	35
Corn Silage	32 tons	240	100	300	50	30
Cotton (1500 lb/in + 2250 lb seed)		94	38	44	11	7
(residue)		86	25	82	24	23

In the year ending June 30, 1979 over 51 million tons of fertilizer materials were used in the United States (3). 1979 use was approximately 600 thousand tons less than the record tonnage used in 1977. A summary of the trend in total U.S. fertilizer usage since 1960 is presented in Table 2. The data shows that fertilizer use, as measured by tons of fertilizer materials, has more than doubled since 1960. In addition to total tonnage increasing the average nutrient content of the materials has increased so that actual increase in plant nutrient use has been even greater. A summary of plant nutrient usage since 1960 is presented in Table 3. This increased plant nutrient content of fertilizer used in the U.S. has resulted from a shift in actual materials used to minimize transportation costs. The principle direct application materials and tonnages used in 1979 for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) are listed in Tables 4-6 respectively. This data is derived from information contained in USDA Publication SPCR7(11-79).

Almost all of the nitrogen fertilizers used in the U.S. derives from anhydrous ammonia, and almost 40% of the N is applied in that form. The other major sources are nitrogen solutions (primarily urea-ammonium nitrate solutions) urea and ammonium nitrate. The balance of the N used comes from sources such as ammonium sulfate, calcium nitrate, sodium nitrate and various mixed fertilizers.

The majority of the phosphorus was applied as a mixed fertilizer though significant quantities of ammonium phosphate and super phosphates (primarily calcium phosphate of varying purities) were applied directly.

Of the approximately 6 million tons of K_2O applied in 1979 about half was applied as potassium chloride and the balance in some mixed form.

Table 2. U.S. consumption of fertilizers. 1960-1969. Source: Crop Reporting Board, USDA SpCr7(11-79).

	Total Consumption of Fertilizer Materials			
Year Ended June 30	Mixed Fertilizers	Primary Nutrient Materials	Secondary & Micronutrients	Total
	1000 tons			
1960	15,650	7,850	1,378	24,877
1965	18,559	11,756	1,521	31,836
1970	20,961	17,331	1,297	39,589
1975	20,647	19,959	1,878	42,484
1976	22,958	23,935	2,296	49,189
1977	24,099	24,999	2,525	51,624
1978	22,110	23,511	1,877	47,497
1979	23,639	25,313	2,080	51,031

Table 3. U.S. consumption of plant nutrients 1960-1979. Source: Crop Reporting Service, USDA. SpCr7 (11-79).

Year Ended June 30	Total Consumption of Plant Nutrients			
	Nitrogen	Available P_2O_5	K_2O	Total
	1000 tons			
1960	2,738	2,572	2,153	7,463
1965	4,639	3,512	2,835	10,986
1970	7,459	4,574	4,036	16,069
1975	8,601	4,507	4,453	17,561
1976	10,412	5,228	5,210	20,849
1977	10,647	5,630	5,834	22,111
1978	9,965	5,096	5,526	20,587
1979	10,643	5,544	6,216	22,403

Table 4. Principal nitrogen fertilizers used in 1979.

Materials	Ave. N Content %	Amount used	N used in that source
	---------------1000 tons---------------------		
Anhydrous ammonia	82	4,883	4,004
Nitrogen solutions	28.7	5,999	1,722
Urea	45.7	2,118	968
Ammonium-nitrate	33.5	2,511	841
N containing mixed fertilizers	10.8	22,003	2,376

Table 5. Principal phosphorus fertilizers used in 1979.

Materials	Ave. P_2O_5 content (% P_2O_5)	Amounts used 1000 tons	P_2O_5 used in that source 1000 tons
Ammonium phosphates	28.7	577	166
Super phosphates	45.1	862	389
P containing mixed fertilizers	19.9	23,123	4,601

Table 6. Principal potassium fertilizers used in 1979.

Materials	Ave. K_2O content (% K_2O)	Amounts used 1000 tons	K_2O used in that source 1000 tons
Potassium chloride	60.3	5,059	3,051
K containing mixed fertilizers	12.9	18,377	2,370

The majority of the K_2O in mixed fertilizers was also derived from KCl.

Fertilizer Use on Major U.S. Crops

Fertilizer use on major U.S. crops is estimated by a number of organizations (4, 5). While some slight differences are found between estimates in general they agree quite well. In this paper the estimates prepared by the Economics, Statistics and Cooperatives Service of the USDA published in "1980 Fertilizer Situation" FS-10 will be used, as they contain the most recent published information.

The actual rates of fertilizer used on crops in the U.S. vary considerably between crops and geographical region. This points out an awareness among farmers and the people making fertilizer recommendations of the differences that exist in the nutrient requirements of different crops, the differences in native fertility of soils between geographical region and the resulting need for fertilizer.

Using corn and soybeans as examples, in 1979 average fertilizer use on corn was 135 lb N, 69 lbs P_2O_5 and 84 lbs K_2O per acre and average fertilizer use on soybeans was 16 lb N, 46 lbs P_2O_5 and 67 lbs K_2O per acre. The main difference in fertilizer use between the two crops was in the nitrogen used. Soybeans are legumes and are capable of symbiotic nitrogen fixation, and thus can supply their own N. Corn however is not capable of N fixation and must obtain its N from the soil. Thus the difference in fertilization patterns reflect differences in crop needs.

N use in Indiana, Illinois, Ohio and Iowa in 1979 averaged 144.8 lbs N/acre. These states, the heart of the Corn Belt, produced about one-half of the U.S. corn acreage in 1979 and all had yields above the national average. Michigan, Wisconsin, Minnesota, Missouri and Kentucky, are on the fringes of the Corn Belt. There yields are normally lower than those of IN, IL, OH and IO and in 1979 their N use averaged only 107.2 lbs N/acre. This difference also reflects a realistic approach on the part of producers to apply fertilizers based on plant needs and only at rates that give a high probability of response.

Finally, differences in the ability of soils in different geographic regions to supply plant nutrients are also reflected in fertilizer use data. In general soils in the north western portion of the Corn Belt are very high in native potassium (K) and little response to additional K_2O is expected. Soils in the eastern portion of the Corn Belt are usually low in native potassium and crops respond well to K_2O fertilizers. In 1979 K_2O rates applied to corn in Kansas and Nebraska, averaged only 27.4 lbs K_2O/A while in Indiana, Illinois and Ohio K_2O rates averaged 106 lbs/acre. Iowa in the middle both geographically and in native K levels used 75.2 lbs K_2O/acre for corn. A similar trend existed for soybeans and wheat.

Data for the average rate of fertilizer used on corn, wheat and soybeans in U.S. since 1975 are summarized in Table 7. Data on the percent of acres receiving fertilizer is also given. Additional data on fertilizer use in individual states for corn, wheat, soybeans and cotton can be found in USDA bulletin FS-10.

The Statistical Relationship Between Fertilizer Use and Crop Yield

Both fertilizer use and corn yields have increased in the past 30 years. Barber and Olson (6) have shown that between 1948 and 1966 nitrogen use and corn yields were highly correlated and presented data

Table 7. Estimates of fertilizer use on corn, soybeans and wheat in the U.S. 1975-79.*

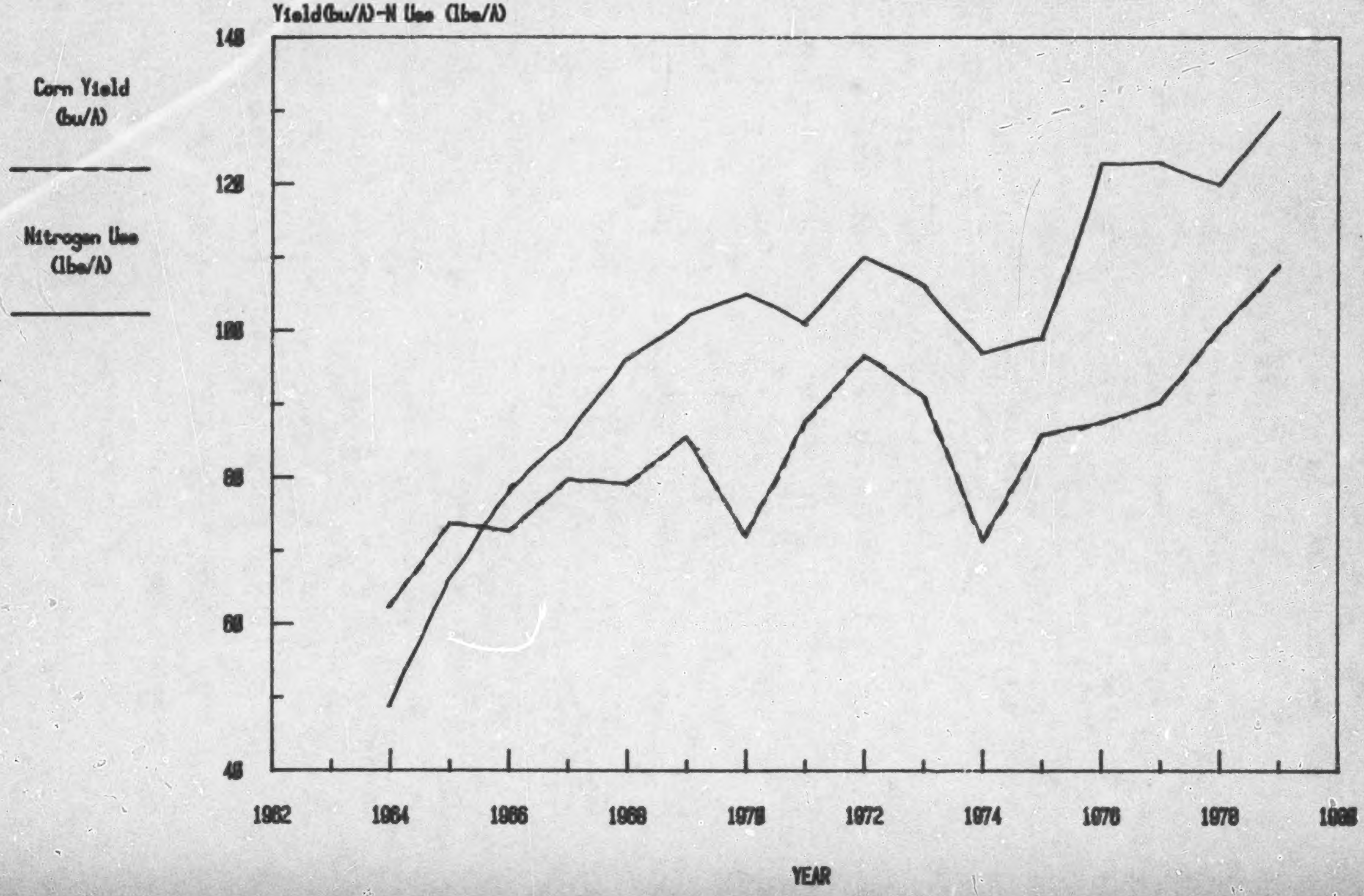
Crop and Year	% of acres receiving fertilizer	Rates used on acres receiving		
		N	P_2O_5	K_2O
Corn				
1975	94	105	58	67
1976	97	127	67	78
1977	96	128	68	82
1978	95	126	68	80
1979	95	135	69	84
Soybeans				
1975	28	15	40	53
1976	31	15	42	50
1977	35	16	45	60
1978	37	17	45	62
1979	40	16	46	67
Wheat				
1975	63	46	35	35
1976	71	51	37	37
1977	65	53	39	41
1978	61	52	35	34
1979	66	54	38	43

Source: 1980 Fertilizer Situation. Economics, Statistics and Cooperative Service USDA Bulletin FS10, December 1979.

from both Indiana and Nebraska to illustrate this point. The increase in corn yields which occurred during that period cannot be attributed only to increased fertilizer use. Advances occurred in other technologies during the same period which also contributed to the yield increases. However the data does indicate that the increase in corn yield and fertilizer use were similar, and since soil fertility and mineral nutrition plays an important role in soil productivity, at least a portion of the yield increases probably results from fertilizers.

Figure 1 illustrates the changes in corn yield and nitrogen use from 1964 to 1979. Similar trends to those observed earlier are seen, and some very interesting observations can be made from this data. One is that yields are still increasing in the United States. 1979 saw the production of the highest national average corn yield on record, over 109 bushels per acre. Also, this crop received the highest rates of N fertilizer ever, approximately 130 lbs N per acre. It is also interesting to observe the similar changes of the two curves, particularly in the 1969 to 1972 periods and the 1972 to 1975 periods. In 1969 both yields and N use were at record levels. In 1970 nitrogen use increased but yields were reduced substantially by a severe outbreak of southern corn leaf blight. In 1971 concern over problems with the disease and tight cash flow situations resulted in a slight decrease in nitrogen use. However yields rebounded when the disease failed to develop, partially due to a rapid shift to corn hybrids resistant to the disease. 1972 saw both increasing N use and increased yields. In 1974 U.S. agriculture experienced an unpredictable shortage of N fertilizers resulting from the formation of OPEC and the resulting embargo of oil shipments

U.S. Ave. Corn Yield & Nitrogen Use



to the U.S. The resulting shortages of N and rapidly rising prices saw N use decrease nationally. Corn yields also dropped markedly that year. Lower N use was not the only factor contributing to the lower yields obtained in 1974, unfavorable weather, also contributed. However, it is interesting to note the similarity in the curves during this period.

While excellent arguments can be made as to the existance of a cause-effect relationship between N use and corn yields on a national basis, the fact that corn does respond to nitrogen in many environments has been illustrated in hundreds of nitrogen response experiments in the United States.

One last point that must be made is that as yields increase, as they are doing, the rate of removal of nutrients from croplands also increases. This in itself will eventually cause mineral deficiencies to limit yields in many U.S. soils unless these nutrients are replaced either by fertilizers or from some other source.

Principals Relating to the Fate of Fertilizers in Soil

In the past century soil scientists have developed a basic understanding of the mechanisms governing the fate of plant nutrients in soils. While many specific questions still exist, enough answers have been generated that the basic reactions which influence the retention of nutrients in soils, and their availability to crops are fairly well understood. Also a basic understanding of how fertilizer reacts in soils and its effects on nutrient cycles has also been developed. The purpose of this section is to define certain basic principles relating to the fate of fertilizers in soils, and hopefully relate this to any effects fertilizers could have on soil productivity.

Nitrogen

Most of the nitrogen present in soils is in the form of soil organic matter, or humus. Soil organic matter is a relatively stable product of the decomposition of plant and animal residues which have been added to soil. Generally, under any particular natural system, or crop production system, soil organic matter achieves some equilibrium level, with decay or mineralization of existing soil organic matter equal to additions to the organic matter pool from the decomposition of crop or other plant or animal residues. Changes in management effect this equilibrium and cause changes in soil organic matter content. Initial cultivation of the virgin soils of the United States resulted in a decrease in soil organic matter content, and subsequent decreases in the amounts of plant nutrients, particularly nitrogen, held in the soil organic fraction. Data from the Magruder plots in Oklahoma illustrate this point. In 1893, the initial organic matter content in the surface 6" of the virgin Kirkland silt loam soil was 3.58% with 0.16% N. By 1978 the organic matter and nitrogen content of the plot cropped continually to wheat which received no fertilizer or manure had decreased to 1.18% organic matter and 0.051% N. An adjacent plot which had received 284 tons of manure from 1898 to 1976 showed a slower rate of decline with an organic matter content of 1.54% organic matter, and 0.054% N.

Data from the Morrow plots in Illinois illustrate a similar trend with soil organic matter levels dropping rapidly in the initial years of the plots and then continuing downward at a slower rate in subsequent years. This was true for plots utilizing a crop rotation which included clover hay as well as corn-soybean rotations and continuous corn, the common cropping sequence found in the corn belt today. Where complete chemical fertilizers were added in 1954 on previously untreated plots, soil organic matter contents increased significantly in subsequent years in both the continuous corn and corn-oat-clover rotation plots. This is probably the result of the increased amounts of crop residues remaining from the higher yielding crops which resulted from fertilizer use.

For crops to be able to utilize the nutrients held in soil organic matter, the organic matter must be mineralized and the nutrients released in an inorganic form. In the case of nitrogen the inorganic forms taken up by plants are ammonium (NH_4+) and/or nitrate (NO_3). Generally most N is initially released from organic materials in the ammonium form, which is subject to conversion in the soil to nitrate, by the process of nitrification.

Mineralization of soil organic matter is a slow process and generally only 1 to 2% of the organic matter in soil mineralizes annually. Thus only a very small fraction of the total supply of plant nutrients held in the soil organic matter become available to plants in any given year.

Using data from the Morrow plots a simple calculation can illustrate the amounts of nitrogen potentially made available each year. In 1973 approximately 3000 lbs of nitrogen/acre was held in the organic matter of the better managed continuous corn plots (those which had received manure, lime and phosphorus). If we use the 2% value for mineralization, probably higher than what actually occurs, approximately 60 lbs of N per acre would be released annually for crop growth. This is considerably less than the 240 lbs of N (Table 1) which are utilized by a high yielding crop of corn, and thus supplimentation in some form is needed to produce crops at todays desired yield levels.

An excellent model of soil organic matter dynamics has been developed in Michigan by Lucas and co-workers and it and much of the background information used in developing the model are explained in the publication "Soil Organic Matter Dynamics" by Lucas and Vitosh (7) and in "Soil carbon dynamics and cropping practices" by Lucas, Holtman and Connor (8).

When nitrogen is added to soil as a fertilizer a number of mechanisms influence the ultimate efficiency with which that fertilizer is utilized by the crop. The form in which the N is added, when it is applied to the crop, the method of application, physical and chemical properties of the soil and fertilizer, and climate all effect the efficiency of nitrogen use.

The three principle nitrogen fertilizers used in the United States today are anhydrous ammonia, urea, and urea-ammonium nitrate solutions. Each have very different properties and react differently with soils.

Anhydrous ammonia is added to the soil as a liquid under pressure and vaporizes immediately to ammonia gas. Thus it must be injected below the soil surface and the soil must close or seal behind the injection tool to prevent gaseous loss of ammonia to the atmosphere. The ammonia gas reacts quickly with the soil water and is rapidly converted to the NH_4^+- ammonium form of nitrogen. Due to the soils ability to hold or exchange positively charged ions like NH_4^+, once the ammonia is converted to ammonium, the potential for loss of the applied N from the soil system is reduced, as long as it remains in the ammonium form. Therefore the initial losses of anhydrous ammonia are primarily gaseous losses of ammonia which occur at or shortly after injection. These losses vary considerably between soils, primarily due to variations in soil texture, water content at time of application and depth of application, but losses from essentially 0 to 5% are most common (2).

Urea is a solid fertilizer material which when added to soils converts to the ammonium form of nitrogen. The conversion of urea to ammonium is catalyzed by the enzyme urease, and results in the production of the compound ammonium carbonate. Ammonium carbonate is a relatively unstable material and can break down and release ammonia gas under certain environmental conditions. If the urea had been incorporated into the soil through some tillage operation this presents little problem. But if the urea fertilizer has been broadcast on the soil surface, as is common in pasture or range production or no-till corn production where tillage is impossible or undesireable, then this release of ammonia gas from the ammonium carbonate intermediate results in a volatilization loss of nitrogen to the atmosphere. Ammonia volatilization from surface applied urea has become a major problem in recent years since urea is now the most widely available solid nitrogen fertilizer, and efforts to control erosion by using reduced or no-till production systems limit the fertilizer placement options available to farmers. Losses as high as 50% of the urea N applied have been observed, with losses from 5 to 15% common when urea is left on the soil surface. Volatilization losses are negligable however when urea is incorporated into the soil.

Once converted to ammonium, NH_4+, urea is held on the cation exchange complex of soils, and unless nitrified, losses of ammonium nitrogen from soils are usually minimal.

Urea-ammonium nitrate solutions are simply solutions of urea and ammonium nitrate salts in water as the name implies. The most commonly used solutions are 28 to 30% nitrogen with essentially half the nitrogen present as urea and half as ammonium nitrate, NH_4NO_3. The liquid urea component of these solutions reacts similarly to the solid urea materials and in the soil converts to NH_4+ ammonium nitrogen. Urea in solutions is also subject to volatilization losses when applied to the soil surface. The ammonium nitrate component of the solutions consists of both ammonium, NH_4+, and nitrate, NO_3-, nitrogen as the name implies. The ammonium component can be retained on the cation exchange complex of soils, however most soils have only limited abilities to retain nitrate, NO_3-, and as a result it moves freely with the soil water. Thus it is subject to leaching losses in periods when water is draining through the soil. Therefore, the 1/4 of the nitrogen in urea-ammonium nitrogen solutions applied in the nitrate form is subject to leaching loss immediately upon application.

From this discussion it is evident that the majority of the nitrogen in fertilizer used in the United States is applied directly as ammonium, NH_4+, or is quickly converted in the soil to ammonium, with the balance applied primarily in the nitrate (NO_3-) form.

There are a number of potential fates for ammonium nitrogen in soils. Among these are:

Uptake and utilization by crops or soil microorganisms;

fixation in minerals in the soil;

conversion to nitrate nitrogen through nitrification;

or ammonium can remain on the exchange complex of the soil indefinitely.

The majority of the ammonium nitrogen in soils will be either absorbed and utilized by higher plants or microorganisms, or it will be converted to nitrate through nitrification. That nitrogen which is taken up and utilized by plants or microorganisms will either be removed from the system by harvesting plants or crops, or eventually be added to the soil organic matter through decomposition of dead residues.

Nitrate nitrogen in soils also has a number of potential fates with the three most important being:

Uptake and utilization by crops or soil microorganisms;

removal from the soil as nitrate by leaching;

loss from the soil as a gas through denitrification.

As in the case of ammonium N, nitrate N adsorbed by plants will either be removed from the system by some removal of the plant material or eventually will be recycled to the soil organic matter.

Leaching, the process of moving dissolved salts through the soil with excess water, moves nitrate nitrogen, which is not held tightly by the soil, through the soil as excess water drains out. Leaching occurs in many soils and is one of the reasons inorganic nitrogen does not accumulate in most soils in the humid regions of the United States.

Denitrification is a microbiological process which occurs under anaerobic or low oxygen conditions. Denitrification results in the stepwise conversion of nitrate nitrogen to N_2 gas, the principle component of the earths atmosphere. Under poorly drained conditions, where soils become saturated and anaerobic conditions are created, denitrification results in the direct gaseous loss of nitrate nitrogen as N_2 or a nitrogen oxide from soils. This process is an important reason why nitrogen fertilizers don't accumulate in the poorly drained soils of the humid regions of the United States.

In arid regions of the United States where denitrification or leaching do not regularly occur nitrogen can accumulate in the soil as nitrate. Because of this potential for nitrogen accumulation in dryer areas soil tests for nitrate are used to measure the nitrogen present and available for crops and this information is then considered in developing fertilizer recommendations in arid or semi arid areas of the U.S. However since regular rainfall precludes nitrate accumulations in more humid areas, these nitrate soil tests are of little practical value in areas east of the Mississippi River.

In summary a simplified schematic nitrogen cycle illustrating some of the major reactions of nitrogen in soils is presented in Figure 2. While symplistic in many regards it does illustrate the major reactions of soil and fertilizer nitrogen in soils.

Phosphorus

The native phosphorus content of most U.S. agricultural soils is relatively low. The total phosphorus content of the surface 6 inches of most soils will fall within the range of 0.01% to 0.10% phosphorus.

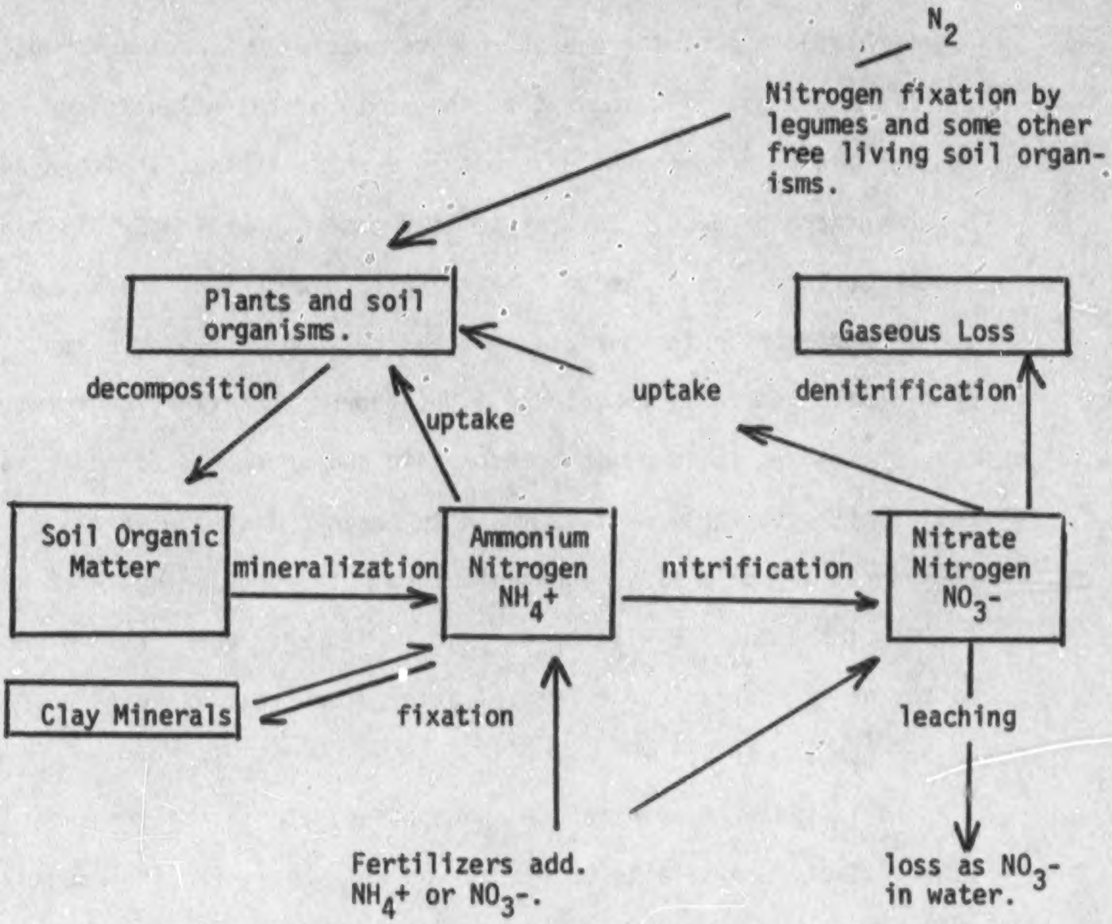

N_2
Nitrogen fixation by legumes and some other free living soil organisms.
Plants and soil organisms.
Gaseous Loss
decomposition
uptake
uptake
denitrification
Soil Organic Matter
mineralization
Ammonium Nitrogen NH_4^+
nitrification
Nitrate Nitrogen NO_3^-
Clay Minerals
fixation
leaching
Fertilizers add. NH_4^+ or NO_3^-.
loss as NO_3^- in water.

Figure 2. A simplified nitrogen cycle.

A generalized map of the phosphorus contents of U.S. soils, prepared by Parker et. al. (9), shows that the soils of the Atlantic and Gulf coastal plains are generally lowest in P while the soils of the Pacific Northwest are highest. In many soils P contents are naturally higher in the surface layers due to P taken up by plants from the subsoil being deposited on the surface in plant residues, or biocycling. Sandy soils generally contain less phosphorus than finer textured soils.

Phosphorus is found in both organic and inorganic forms in soils. Unlike nitrogen where most is found in organic matter, the majority of the phosphorus in soils is in inorganic form. In most agricultural soils 20 to 40% of the total P will be in organic matter. Whether in organic matter or in inorganic form P will exist almost exclusively in soils as an orthophosphate (9).

As in the case of nitrogen, phosphorus held in soil organic matter is relatively unavailable to plants and must be mineralized to an inorganic form to be adsorped by plants. The primary forms of phosphorus taken up by plants are $H_2PO_4^-$ and $HPO_4^=$ dissolved in the soil solution. Normally the concentration of phosphate in soil solution will be less than one part per million. Thus the supply of phosphate to the soil solution must be renewed quickly and solubility of inorganic phosphates is to a large extent the factor which determines the availability of soil phosphorus.

The basic inorganic forms of phosphorus in soils are: minerals such as apatite; calcium phosphates; iron and aluminum phosphates; and occluded phosphates or phosphates coated by iron and aluminum oxides or hydroxides. Generally as soils weather, or age, the relative concentrations of various inorganic phosphates change (11). In slightly weathered soils, characteristic of the northern and western edges of the Corn Belt, the majority of the inorganic phosphorus is present as calcium phosphates with only small amounts of iron or aluminum phosphates. In moderately weathered soils such as those found in the majority of the Corn Belt, significant quantities of calcium, iron, aluminum and occluded or coated phosphates are found, while in highly weathered soils, such as those found in the southeast and Hawaii, the majority of the phosphate is in iron, aluminum and occluded forms.

In general terms, as weathering increases and iron and aluminum hydroxide content of soil increases, the potential for fixation or limitations on the availability of native and added phosphorus increases. Soil pH then becomes extremely important in influencing the solubility of various iron and aluminum compounds and phosphorus availability. In general, pH ranges from 5.5, slightly acid, to 7, neutral, are associated with greatest phosphorus availability.

Most phosphorus fertilizers are classified into three groups based on solubility (12). The first group are those in which the phosphorus is soluble in water, the second are those not readily soluble in water but soluble in ammonium citrate solutions and the third are those insoluble in water or ammonium citrate. While fertilizers may differ greatly in there solubility within certain limits this is not a serious concern because all commercial chemical phosphorus fertilizers will react with the soil within a few days. Of more critical concern is the availability of the phosphorus which has reacted with the soil.

Most phosphorus in fertilizer is in the forms of calcium, ammonium or potassium phosphates. These compounds have extremely different properties and their initial reaction products in soils are also somewhat different, but in simplistic terms, the following chain of events occurs. The phosphorus fertilizer dissolves and a saturated solution of varying pH and composition moves from the pellet, assuming a solid material is used. Depending on the material used, the pH can vary from 1.5 to 10.1 while the P concentration can vary from 1.5 to 6 M. The phosphate then reacts with the soil and a number of crystaline compounds are formed and precipitate out. These products remain for various periods of time before calcium or iron or aluminum phosphate compounds are formed, depending on the soil pH and the relative concentrations of calcium and iron and aluminum in the soil. In general, the initial reaction products are of much higher solubility than the calcium, iron or aluminum phosphates which form later. Thus a zone of relatively high phosphorus availability immediately around the phosphorus fertilizer material is established, with this increased availability lasting for varying amounts of time depending on the amount of fertilizer added, the method of application, form of fertilizer used and soil properties.

Generally the recovery of phosphorus fertilizer in the year applied is relatively low. However, this is not necessarily bad as the residual fertilizer increases the soil nutrient supply and is available for subsequent crops. Since the reaction products of phosphorus fertilizers are relatively insoluble materials little leaching of phosphorus occurs and losses of phosphorus from agricultural lands are more related to erosion and actual removal of soil than to losses in drainage waters or as gaseous products.

A simplified phosphorus cycle is presented as a summary in Figure 3.

Potassium

The total potassium (K) content of most U.S. agricultural soils is quite high, from 0.3% to 2.5% K (9). Generally the potassium content of soils is a function of the parent material in which the soil is formed and the degree of weathering. Soils of the coastal plains of the U.S. are formed in materials which were initially low in potassium, and then were highly weathered. Thus these soils are low in both total potassium and plant available potassium. Soils in the Western U.S. however, were formed in materials high in potassium and are in general, less highly weathered and have higher total and plant available potassium contents.

Unlike nitrogen and phosphorus, essentially no potassium is found in soil organic matter and almost all is in an inorganic form. Soil potassium is often divided into three categories: nonexchangeable, exchangeable and water soluble. In most soils the majority of the soil potassium is in the nonexchangeable form, primarily feldspars and micas. In many soils 90% or more of the total potassium content is in a nonexchangeable mineral form.

As discussed in a previous section, soils have the ability to exchange positively charged ions and potassium, K+ is such an ion. Thus exchangeable potassium is the K+ held or retained on the soil cation exchange sites. In agricultural soils ranges of from 100 to 1000 lbs of exchangeable potassium per acre are common, with the lower levels found in the eastern U.S. and higher levels in the West. Water soluble potassium is potassium dissolved in the soil solution.

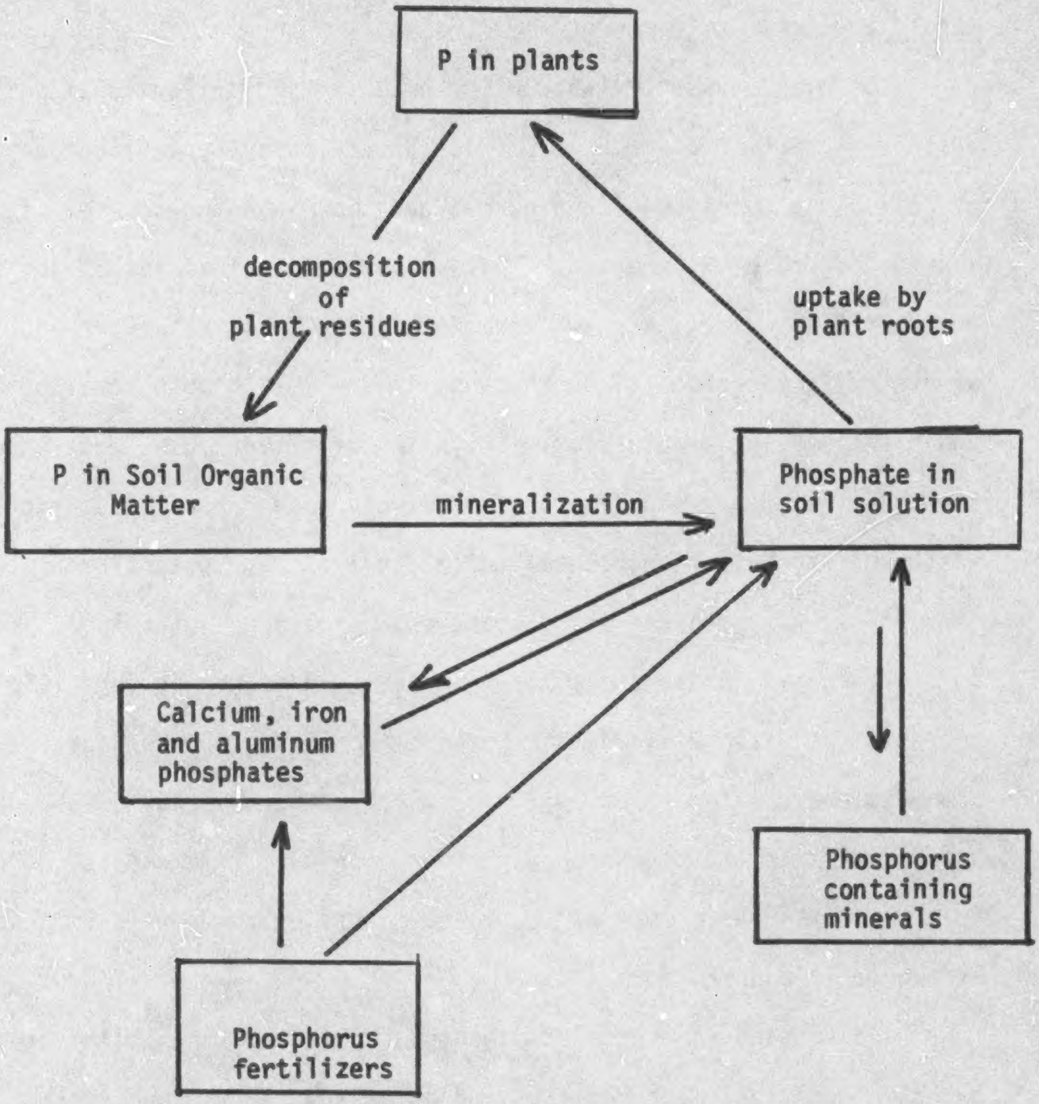

P in plants
decomposition of plant residues
uptake by plant roots
P in Soil Organic Matter
mineralization
Phosphate in soil solution
Calcium, iron and aluminum phosphates
Phosphorus containing minerals
Phosphorus fertilizers

Figure 3. A simplified phosphorus availability cycle in agricultural soils.

Generally, the exchangeable and water soluble potassium is the potassium in soils available to plants. As these available forms are depleted by plant uptake or, in low exchange capacity soils by leaching, weather will release some of the nonexchangeable K.

Potassium fertilizers are primarily potassium chloride salts, with smaller quantities of potassium sulfate and potassium nitrate used. Regardless of source, potassium fertilizers dissolve in the soil solution upon application to soils and the K+ is then subject to exchange on the soils cation exchange sites. In soils with large quantities of mica type clay minerals a portion of the potassium can be fixed in the clay mineral lattice in a non-available, nonexchangeable form. In general this fixed potassium will only be released by weathering of the minerals.

A simplified diagram of potassium relations in soils is illustrated in Figure 4.

AVAILABLE DATA ON LONG TERM FERTILIZER EFFECTS ON SOIL PRODUCTIVITY

Organizations Conducting Long Term Fertilizer Research

The majority of the data available today on the long term fertilizer effects on soil productivity has been generated by the Land Grant Universities and state Agricultural Experiment Stations. A number of long term fertilizer experiments are currently underway. One problem in assembling and utilizing this data however, is that it is not regularly summarized and when published is usually published in University or Experiment Station bulletins or mimeos of only limited distribution.

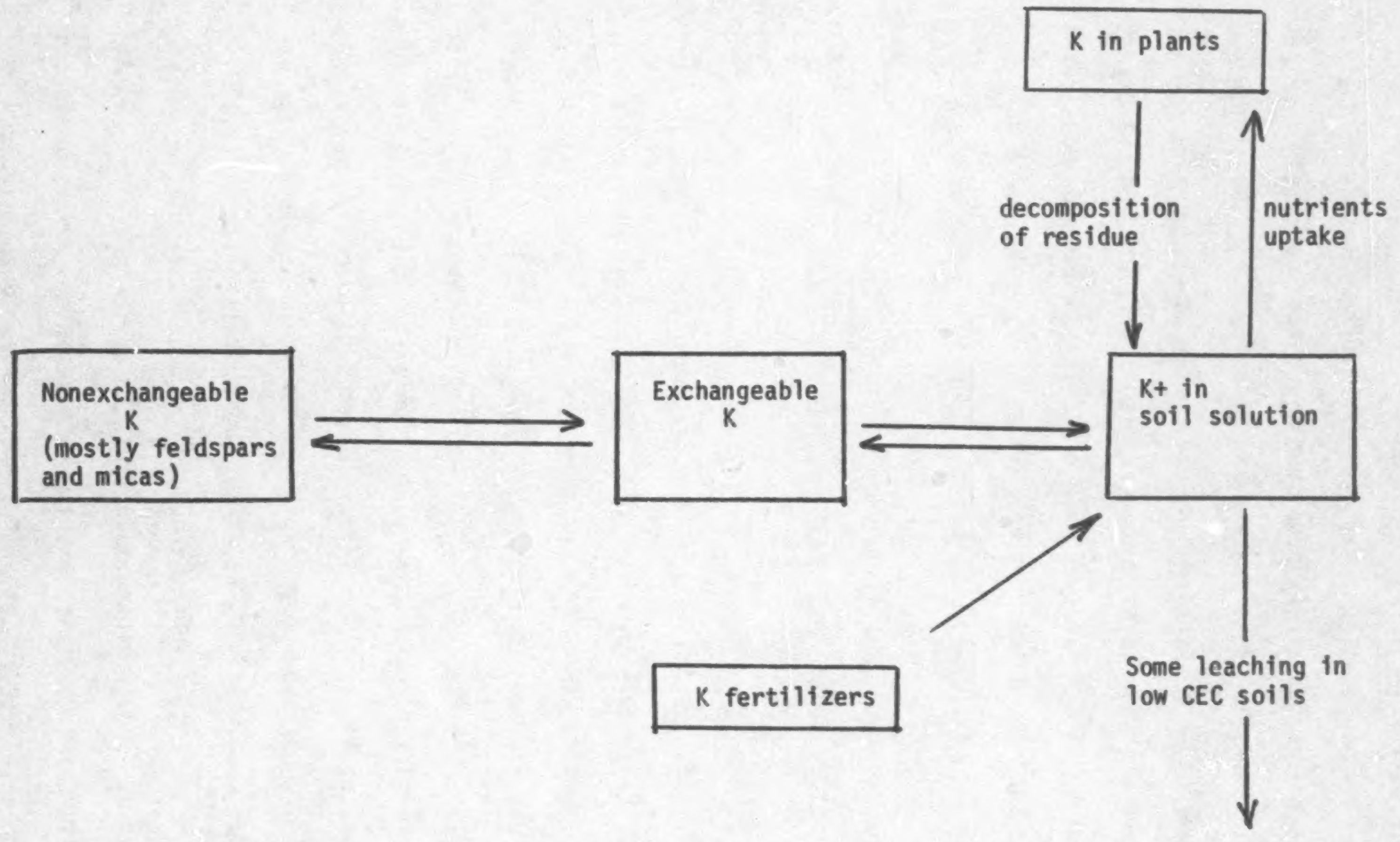

K in plants
decomposition of residue
nutrients uptake
Nonexchangeable K (mostly feldspars and micas)
Exchangeable K
K+ in soil solution
K fertilizers
Some leaching in low CEC soils

Figure 4. A simplified diagram of potassium dynamics in soils.

This is even a bigger problem when trying to utilize results of industry or private research. In most cases this information is not published in places where it is widely available. Generally this is due to lack of incentive to publish these results, or lack of a suitable vehicle, or concern over the rights to utilize research.

In the case of University and Experiment Station data the same lack of incentive can exist. In many cases these long term experiments are a very low priority item today, and since trends established in the first few years of an experiment may change very little in subsequent years, publication of up to date research summaries are not highly emphasized. The availability of a suitable vehicle of national scope to publish such data is a real problem in these experiments also.

One other organization which must be noted is the National Fertilizer Development Center, TVA, which does a tremendous amount of fertilizer and fertilizer related work. While the majority of their work deals with the development of new or improved fertilizer materials or manufacturing processes, they also do a considerable amount of testing of fertilizer materials as to their effects on soils and plants.

The Types of Experiments Being Conducted

There are four basic types of soil fertility experiments conducted in the field from which data is generated concerning crop responses to fertilizers, and fertilizer effects on soil productivity.

The first type are experiments designed to study the response of crops to fertilizers in the year applied. While these experiments may be concerned with the effect of native or existing soil fertility on fertilizer response, or the effects of other soil or management factors on a fertilizer response, they are primarily designed to study specific, direct fertilizer responses and are generally conducted for a relatively short period of time at a particular site to minimize residual effects. Examples of this type of experiment are: fertilizer rate studies used to determine optimum fertilizer rates for different crop cultivars, or management systems; some types of soil test calibration studies; experiments studying methods of fertilizer placement or new fertilizer materials. There are literally hundreds of experiments of this type conducted each year by Universities, Agricultural Experiment Stations, Research Institutes, State and Government Agencies and private industry.

The second type of experiments involve longer term experiments designed to look at both direct and residual effects of fertilizers on crop yields and soil productivity. These may be conducted for anywhere from two to twenty years or longer and are designed to look at residual effects of fertilizers on crop yield and soil fertility levels. The results of this type of experiment are commonly used to calibrate soil test procedures and establish fertilizer rate recommendations for elements such as phosphorus and potassium which have significant residual effects. The majority of this type work has also been done by the State Agricultural Experiment Stations, though in recent years industrial groups involved in soil testing and fertilizer recommendations have begun to conduct work in this area.

The third type of soil fertility experiment is the long term study designed to look at fertilizer effects on crop production but also incorporating other crop production variables such as crop rotations, tillage systems, or the use of animal manures in combination with or in place of fertilizers. In many ways these experiments compliment the preceeding types in terms of establishing regional fertilizer rates for various cropping systems or alternative production systems. Again these experiments are primarily being conducted by the State Agricultural Experiment Stations.

The fourth type of experiment is the very long term classic experiments established prior to 1900 and designed to look at changing technology on crop production and soil productivity. These experiments, while only a very few are left today, provide a wealth of data and tremendous opportunity to make detailed studies on specific questions relating to fertilizer and cropping system effects on soil productivity. Examples of this type experiment are the Morrow plots at the University of Illinois, the Sanford plots at the University of Missouri and the Magruder plots at Oklahoma State University. The Jordan plots at the Pennsylvania State University were lost recently to construction of a dormitory, however much valuable information is available from this experiment. One major problem has been that the importance of these long term plots has only recently been recognized and many old experiments such as the Jordan plots were lost to campus expansion programs or lack of interest or funds. In fact in many cases only after having these plots placed on the national register of historic places has there future been secured.

Some Representative Examples of the Types of Long Term Research Being Conducted

While much important information can be obtained from each type experiment only the multi year experiments really address the question of the long term effects of fertilization on soil productivity. Some of the long term experiments conducted previously or currently being conducted are summarized below. This by no means is a total list of the data available but rather serves as a representative sample of the types of data available. The list is organized by experiment type and geographic region. Where published data are available appropriate literature citations are made.

Classic Experiments

Three classic experiments which provide valuable information on the long term effects of agricultural technology on productivity are currently being conducted. These are the Morrow plots at the University of Illinois, the Magruder plots at Oklahoma State University and the Sanborn Field at the University of Missouri. One other experiment which was conducted for many years was the Jordan Plots at the Pennsylvania State University. Unfortunately, though this experiment was terminated in the 1960's, much valuable data is available.

The Morrow Plots were initiated in 1876 by professors Miles and Morrow, and are the oldest agronomic research plots in the United States and contain the longest term continuous corn plot in the world (13). Of the original ten one-half acre plots, parts of three exist today. On these plots three basic cropping systems are followed: continuous corn; a corn-oat/corn-soybean rotation; and a corn-oats-clover rotation.

In 1904 the main plots were subdivided and fertilizers were introduced as a variable within each cropping rotation. The initial fertilizer treatments consisted of additions of limestone, barnyard manure and either ground rock phosphate or steamed bone meal as a phosphorus source.

These treatments were continued through 1925 when the phosphorus additions were discontinued. Manure additions were continued annually, however and limestone was applied in 1919, 1943 and 1949.

In 1955 significant changes were made and chemical nitrogen, phosphorus and potassium fertilizers were first added. In 1967 the use of soil tests as a means of predicting fertilizer need was introduced into the study and two levels of fertilizer treatment were started. Thus today a wealth of information on the residual effects of these various inputs on soil properties and crop growth exist. Data collected include organic matter, total nitrogen, physical properties and nutrient status, in addition to crop yields.

The Magruder Plots were initiated in 1892 at Oklahoma A and M College by A.C. Magruder, the first professor of Agriculture (14). Wheat was planted on a virgin prairie soil and has been planted continuously since. Beginning in 1899 manure was applied about every fourth year on one-half the area. In 1930 chemical fertilizer treatments were begun. In 1947 the plots were physically moved to a new location to facilitate construction of a new dormitory. The current plots consist of six treatments testing the use of fertilizers, lime and manure on wheat production. In addition to wheat yields, soil properties such as organic matter content, total nitrogen and available nutrients are measured.

The Sanborn Field was established in 1888 on the campus of the University of Missouri (15). Of the original 39 plots three have received chemical fertilizers since the beginning of the experiments. Unfortunately no detailed summaries of the Sanborn Field have been prepared in recent years so while much data is known to exist its use is severely restricted.

The Jordan Plots, initiated in 1881 at the Pennsylvania State University, were the oldest fertilizer experiments in the United States (16). From these plots came observations which led to research giving us many of the basic concepts we now use in soil science. From the beginning chemical fertilizers were applied alone and in combinations with limestone and manure. Unfortunately these plots were terminated in the 1960's, however a 75 year summary is available.

A number of other long term experiments were conducted at various locations at the same time these four experiments were initiated. Unfortunately though, many were terminated before chemical fertilizers became widely available.

Long Term Fertilizer Experiments Designed to Look at Residual Effects of Fertilizers on Soils

Fortunately a large number of long term soil fertility experiments have been conducted through out the United States and from these experiments important concepts dealing with fertilizer effects on soils can be drawn. Some examples of this type of experiment are:

A nitrogen experiment conducted by S.A. Barber in Indiana with corn designed to look at the residual or carry-over effects of the nitrogen fertilizer on subsequent corn crops (17).

Long term nitrogen rate studies on corn conducted in Ohio (18), Iowa (19) and Minnesota (20). These studies show long term responses of corn to nitrogen fertilizers within these climatic regions. Examples of similar studies can be found on many other crops throughout the U.S.

Crop response and changes in soil content of P and K with long term fertilization. Examples include work of Barber in Indiana with a corn-soybean-wheat rotation (21), work of Rehm et al in Nebraska (22) with both continuous corn and continuous wheat, Allen et al in Louisiana on Bahia grass (23), Meyer and Beason in Kansas on various rotations (24), Gwin in Kansas on irrigated continuous corn (25), Kamprath in North Carolina on corn and soybeans (26), and Vitosh et al in Michigan on corn (27). All of these studies are long term rate studies designed to look at both the optimum rate of P and/or K needed on various crops but also the effects of soil P and/or K levels on crop response to fertilizer and the long term ability of soils to continue to supply the nutrients needed for crop production.

This type of basic response experiment provides data for both determining the rate of fertilizer needed for a particular crop at a particular yield level and also measuring the residual effects of the fertilizer treatment on the soil. The data is commonly used to calibrate soil tests used to predict fertilizer needs. While a large number of experiments of this type are conducted each year in the United States the need for this type data constantly increases due to the changes occuring in other technologies, such as plant genetics, which alter the responses obtained and in some cases can effect basic soil properties. Thus to keep fertilizer recommendations up to date in light of changes in other technologies these experiments must be continued.

In addition to these experiments cited as examples of experiments designed to look at fertilizer use alone, a number of other experiments are conducted to study the interaction of other management factors with fertilizer use on soil productivity and crop yields. Some examples of this type experiment are:

The use of animal wastes to suppliment or replace chemical fertilizers where wastes are available. Examples of this type experiment are those conducted by Vitosh and co-workers in Mighigan (28), Baldock and Musgrave in New York (29) and Parks and Safley in Tennessee (30).

The use of cover crops in a cropping system as a means of either producing additional N or trapping residual N. The work of Kamprath and others in North Carolina (31) is an example of this type approach.

The effect of tillage-system on plant nutrition is also receiving much study. The work of Randall in Minnesota (32) is an example of this.

The effect of soil pH on fertilizer response as illustrated by the work of Peevey et al in Louisiana (33).

All these experiments cited are examples of the types of work which has been done and from which information can be drawn.

The available data base is large and while every conceivable hypothesis has not been tested, a basic understanding of the soil-plant system, as described earlier, has been developed. This is not to say additional research is not needed, but rather that now that we are beginning to understand the basic concepts, we have the opportunity to utilize this understanding to develop more efficient fertilization systems, to sustain and hopefully increase the productivity of our soils, and to minimize any adverse effects fertilizer use could have on the environment. This is the direction agronomic research has taken the last few years, and will continue to take, as we are faced with continuing shortages of natural resources, and increasing demand for food and fiber.

THE CONSEQUENCES OF CHEMICAL FERTILIZER USE ON SOIL PRODUCTIVITY

While a tremendous amount of research has been done on the use of fertilizers in the past century, some basic concerns still exist. These concerns are most commonly expressed in two general areas: What effects will fertilizers have on the sustained productivity of soils; and what effect will long term fertilizer use have on the environment, especially water quality.

The Effect of Long Term Fertilizer Use on Mineral Nutrition and Yield Level

The production of agricultural crops at our current yield levels requires the availability of considerable quantities of plant nutrients. Unfortunately the native fertility of many, if not most agricultural soils today is not adequate to totally meet this demand. The resulting deficit is routinely made up through the use of chemical fertilizers, or where available, animal, industrial or municiple wastes. Considerable data exists demonstrating the importance of supplying these supplimental nutrients to maintain soil fertility and productivity. The two best examples of this can be drawn from the Morrow and Magruder plots.

On the Morrow Plot crops have been grown continuously since 1876. Corn yields have decreased from 1888 till 1930, regardless of rotation used, when no supplimental plant nutrients were applied. Beginning in 1904 barnyard manure, phosphorus and limestone was applied, and corn yields increased markedly. By 1978 the yields were approximately three times those of 1904 in each of the cropping systems. The yields in the untreated plots increased from 1930 to 1978 due to other improved practices, but the rate of increase was much smaller as compared to where nutrients were applied.

The addition of chemical fertilizers beginning in 1955 resulted in higher corn yields on all cropping systems. Applying lime and chemical fertilizers to plots which had received no supplimental nutrients since the plot was initiated resulted in yields almost as high as on plots where manure, phosphorus and lime had been applied since 1904.

Similar trends were observed in the Magruder plots in Oklahoma. Virgin prairie was first planted to wheat in 1893. Wheat has been grown continuously since, with no fertilizer applied during the first five years. Manure was first applied to one-half the plot in 1898 and a total of 284 tons of manure per acre have been applied since. Wheat yields were approximately 12 bushels per acre on the untreated check plot from 1899 through 1947, while in the manured plots they averaged approximately 20 bu per acre. The addition of chemical fertilizer in 1930 to previously untreated plots produced yields comparable to those where manure had been applied since 1898. This trend remained until approximately 1960 when the plots receiving both nitrogen and phosphorus fertilizers began producing higher yields than those receiving manure only. Since 1960 this trend has continued with yields in the plots receiving chemical nitrogen and phosphorus fertilizers being about 6 bushels per acre higher than those receiving manure only and double those which have received no fertilizer or manure since 1893.

These two experiments illustrate the importance of supplemental nutrients either through manure or fertilizers in maintaining soil productivity. They also illustrate that the addition of fertilizers, to previously rundown or nutrient depleted soil, can restore soil productivity, if mineral nutrition is the factor limiting crop growth.

This is not to say that fertilizer applications will result in increased yields, every where, every year. This is definitely not true. However what the data from the Morrow and Magruder plots does show is that over time crop production depletes soils of necessary plant nutrients and unless they are replaced, mineral nutrition will become limiting and productivity will decline. The amount of time required for nutrients to become limiting is a function of the crop being grown, the fertility of the soil and the nutrient involved.

Nitrogen

As discussed previously, most of the nitrogen in soils is in the form of soil organic matter and must be mineralized to ammonium or nitrate before it can be utilized by plants. Cultivation of a virgin soil results in a reduction in soil organic matter over time and a decrease in the amount of plant nutrients mineralized as organic matter levels decrease. Data from the Morrow and Magruder plots clearly illustrate this point. Soil organic matter levels have decreased from 3.58% in 1893 to 1.18% in 1978 on the untreated portion of the Magruder plot. Where manure was applied the decrease was less, with 1.54% organic matter present in 1978. Even though the soil organic matter has decreased continually since 1893, no response to applied nitrogen was obtained until about 1960, at which time the soil organic matter content had dropped below 1.5%.

A similar trend was seen in the Morrow plots with soil organic matter and nitrogen levels decreasing over time irregardless of cropping system used. However, one interesting point is that when chemical fertilizers were applied to previously untreated plots, in both the continuous corn and corn-oats-clover rotations, soil organic matter contents increased markedly. This was the result of increased crop residue production from the fertilized crops.

With the exception of the nitrogen that finds its way into soil organic matter, the residual effect of nitrogen fertilization is relatively short. This can be illustrated by work of Barber in Indiana (17), presented in Table 8. This work shows that while some significant residual effects of nitrogen fertilizer can occur for two or three years, by the fourth year residual effects are essentially gone. This work illustrates that residual nitrogen does contribute to yield, and that nitrogen fertilizer recommendations should consider the management given the preceeding crop. The amount of carry-over, however, will depend on N rate applied, yield obtained, soil properties, and weather. Thus carry-over effects are difficult to assess. In Indiana, more recent unpublished work of Barber would indicate that the residual soil nitrogen available, following a well fertilized corn crop or soybean crop are equivalent to a direct application of sixty lbs of nitrogen fertilizer.

In more arid regions of the U.S., where nitrogen losses are less, it is common to use a soil nitrate or ammonium plus nitrate test to

Table 8. Response of continuous corn to annual applications of nitrogen. Barber (17).

Rate of N [1/] applied lbs/acre	Corn yields bu/acre 1960	1961	1962	1963
0	115	69	55	39
50	135	118	112	75
100	139	141	146	108
150	146	141	161	135
200	148	142	156	157

[1/] All plots were treated uniformly in 1959.

measure residual or carry over nitrogen directly. The available soil nitrogen level is then considered in the fertilizer recommendation. In the humid areas of the U.S. where losses of N from soils by leaching or denitrification are high, this has not been an effective tool.

One potentially adverse effect of nitrogen fertilizer use on soil productivity is the acidifying effect on soil pH. This was first recognized in the Jordan plots in Pennsylvania where ammonium sulfate fertilizer had been used continually for forty years. The residual acidity produced by the ammonium sulfate fertilizer, reduced soil pH from 5.6 to 4.5. Yields of corn, wheat and hay were severely reduced. The application of limestone to neutralize the acidity, resulted in increased yields and restored soil productivity.

The nitrogen fertilizers used today are acid forming. This can be a benefit or a potential problem depending on the soil. In naturally alkaline soils, acid forming fertilizers can increase the availability of phosphorus and micronutrients, such as zinc or iron, and increase productivity. However in naturally acid soils, acid forming fertilizers can further lower pH. This can reduce yield and productivity unless lime is applied to neutralize the acidity. Thus depending on soil properties and management, the residual acidity formed could be a potential problem, but one that is easily dealt with.

In summary, while some residual effects of nitrogen fertilizer use are found, they are usually relatively short lived, with the exception of the effects on soil organic matter content. Thus in those cropping systems where mineralized soil nitrogen is not adequate to supply crop needs nitrogen must be supplimented annually to maintain productivity.

Phosphorus

Unlike nitrogen which has a relatively short residual activity in soils, phosphorus tends to accumulate in soils in relatively insoluble inorganic forms. Thus phosphorus fertilization leads to increased soil phosphorus levels over time. Data from a long term phosphorus and potassium experiment conducted by Barber in Indiana (21) illustrates this point. After 25 years of fertilization, soil test phosphorus levels directly reflect the rate of phosphorus applied. Where no P was applied soil test P levels were 14 ppm, where 25 lbs P_2O_5/A/yr were applied soil test levels were 30 ppm, where 50 lbs P_2O_5/A/yr were applied soil test levels were 40 ppm and where 100 lbs P_2O_5/A/yr were applied soil test P levels were 89 ppm. Barber concluded that on that particular soil yield responses were primarily due to the residual effect of phosphate fertilizers building soil P levels. His work also showed that 50 lbs of P_2O_5/A/yr gave near maximum yields for corn, soybeans and wheat, and that 200 lbs P_2O_5 per acre could be applied once every four years and be as effective as an annual application of 50 lbs/acre. In many intensively managed soils, particularly where high value crops such as vegetables are grown, phosphorus levels in the soil have become quite high. The questions then asked are at what level is soil P high enough that no additional P is needed, and how long can soil reserves adequately supply plant needs. Work by Vitosh and co-workers in Michigan (27) addresses these questions. Beginning in 1973 phosphorus was applied at rates of 0, 50, and 100 lbs of P_2O_5 per acre per year to irrigated corn grown on a soil with a very high soil P level. Through 1979 no response to added P has been obtained. This indicates that in soils with very high soil P tests, soil P levels can be adequate for crop production. Fertilization emphasis then shifts when soil P levels are high from supplying the P needed for crops, to maintaining soil P at a level adequate for optimum crop growth.

This is of real practical significance since summaries of soil test reports from many states indicate that soil P levels are increasing, and in many instances have become adequate to supply the P needed for crop production. Thus, it is conceivable that unless some change in technology requires an increase in soil test P levels, P use could level off as the P level in more soils rises to that adequate for high yielding crop production. In fact P use is increasing at a slower rate today than either N or K reflecting these changes in fertilizer need.

In summary, phosphorus, unlike nitrogen, accumulates in soils and with long term fertilizer use soil levels can become high enough to supply crop needs. Thus native fertility can be enhanced and productivity increased over time as P levels increase. This is occurring in many parts of the country, particularly where high value crops are grown and fertilizer use is high. Thus the productivity of many soils has increased as residual P levels have increased.

Potassium

Like phosphorus, potassium can accumulate in soils when added over time in fertilizers. Research has shown that in humid areas of the U.S., inherently low in K, soil tests can reflect this accumulation of K and yields can be enhanced by K application. Work by Barber in Indiana (21) and Kamprath in North Carolina (26) illustrate this point. However high soil potassium levels in many soils of the eastern U.S. may not supply adequate K for extended periods, and soil reserves tend to become depleted faster than corresponding soil phosphorus levels. For this reason Barber recommends K applications every two years as a minimum, as compared to every four years for phosphorus.

This is in contrast to the situation found in the Western U.S.. Many soils in the more arid regions contain adequate potassium levels, and potassium fertilization can actually decrease yields. Work of Rehm and associates in Nebraska (22) illustrates this point. Thus care is needed to ensure that adequate potassium is applied on soils with low natural K levels, but not on soils where it is not needed.

The Effects of Fertilizer on Environment

A significant portion of our water supplies pass through and are effected by agricultural lands. Fertilizer has been shown to effect water quality, particularly the use of nitrogen and phosphorus fertilizers. Since this subject has received extensive study in recent years and has been reviewed in numerous books, papers and symposia a detailed review will not be made here. Rather, certain key points will be made as they apply to fertilizers. An excellent review of the subject can be found in the proceedings of the symposium "Cycling of Mineral Nutrients in Agricultural Systems" edited by Frissel (34).

Nitrogen Lost to Surface Waters

Most of the nitrogen removed by surface runoff is organic nitrogen associated with sediment. While it is possible to get significant losses of fertilizer nitrogen in surface runoff if heavy rains immediately follow a surface application of fertilizer to a soil, this mechanism accounts for only a small proportion of N lost from soils or of the fertilizer N applied.

The rate of fertilizer nitrogen applied to crop lands can influence the amount of nitrate leaving fields via subsurface waters or tile drainage lines. When the percentage of the applied N utilized by the crop decreases, the amount available for leaching increases. Depending on the soil, this may or may not present problems to water quality. While fertilizer use on cultivated crops, particularly at rates above what can be utilized by the crop, can increase the nitrogen loss from soils, how this effects nitrogen concentration in streams is still unclear. Depending on the characteristics of the individual watershed relating to the transfer of water from soil to stream, nitrates in the water may or may not contribute to the nitrogen concentration of the stream. The amount of unutilized fertilizer nitrogen leaving pasture and range lands has received relatively little work since only low rates of fertilizer are normally used and recovery in crops is high. However fertilizer nitrogen can be lost in drainage water from these systems also.

Nitrogen Lost to Ground Water

The amounts of fertilizer nitrogen either lost to, or found in transit to, ground water are quite variable. In general, in the Southeastern U.S. nitrate enrichment of shallow ground water has been shown to occur, though no enrichment of deep ground water is known. Denitrification of nitrate in shallow ground water also has been noted. In the midwest significant amounts of nitrogen can be found below the root zone but whether this N actually enters ground water reserves, or is denitrified, is still in question.

The problem of leaching of nitrates from fertilizer to ground water is greater in the irrigated areas than in other areas of the U.S. As in other parts of the country, the role of denitrification in removing these nitrates prior to introduction into the ground water is not fully understood.

Phosphorus Lost to Surface Waters

Only a very small amount of fertilizer phosphorus added to croplands is lost from soils, if erosion is controlled. However though small, from a water pollution standpoint these amounts can be significant. The principal problem is the loss of phosphorus in sediments, which can be minimized through proper erosion control measures and soil conservation techniques.

Phosphorus Lost to Ground Waters

Although some P is lost by movement into ground waters through leaching, the amounts are so small that these losses are insignificant from both agronomic and water quality standpoints except for some very unusual circumstances.

THE ADEQUACY OF THE DATA BASE TO MEET TODAYS NEEDS

In general the research conducted over the past century has given us a basic understanding of fertilizers, their effects on soils and their role in soil productivity. Many of these basic concepts have been covered in this report. However, as technologies change and new fertilizers are developed, much additional research will be needed to determine exactly what effects these changes will have on the soil-plant-water system as we know it.

In the past few years we have developed a widespread concern for our environment and the potential effects of materials such as fertilizers on it. While we have been able to develop a good qualitative understanding of the problem by applying our basic knowledge of the reactions of fertilizers in soils, much work is needed to improve our quantitative assessment of the problem.

Today major research efforts are expended to develop models which will explain or predict the fate of fertilizers in the environment. Most models are built on basic information drawn from the literature. The precision of some of the basic information used is not adequate to meet the needs of the model. In some cases this lack of basic data has restricted the development and utilization of models. One valuable spin-off from these modeling efforts however has been the pointing out of specific research needs.

Some basic constraints also exist which can inhibit the regional analysis of many of these subjects. Principly these constraints include basic differences in soils, climate and management systems. These differences make the task of developing regional models to assess both the effects of fertilizer use on corn, grown on acid soils, under high rainfall, and the fertilizer use on wheat, grown on alkaline soils, under a arid climate, in the same model very difficult. This is not to say that such models are impossible to develop, but rather, time consuming and difficult at best.

Regional research projects in fertilizer use have been conducted for many years, and have contributed much to our basic knowledge of soils and fertilizers. An example is the regional soil test committee which has worked to standardize applicable soils test procedures, exchanged ideas and experiences and done much to improve the precision of soil testing and the interpretation of those tests.

From a practical standpoint two basic tools are available to farmers and their advisors to determine the fertilizer needs of a particular area. These are soil testing and plant analysis. Soil testing is simply a chemical test to estimate the amount of plant available nutrients present in the soil. From these tests fertilizer recommendations are then made based on calibration studies conducted on similar soils. The key aspect of soil testing is the basic calibration data. It is important that this work be kept current in light of changing technology. Also that calibration studies not be extrapolated to soils which have widely differing physical and chemical properties.

Today soil tests are used widely as a basic tool in making lime, phosphorus and potassium recommendations throughout the U.S., and nitrogen recommendations in the western U.S. In general if one utilizes a regular soil testing program, soil pH and fertility levels can be maintained for maximum productivity. The use of plant analysis, particularly as a tool to monitor secondary and micronutrient needs, further improves the reliability of the total soil fertility program. In 1979 over three million soil samples were analyzed in the United States.

One problem which has developed in the process of making fertilizer recommendations has been that some soil testing laboratories consistantly recommend more nutrients than are needed based on University calibration studies. As a means of correcting this problem two approaches are being used.

In Nebraska a program of comparing recommendations from various labs, by sending duplicate soil samples to all labs for analysis and then following their recommendations in a field study was initiated in 1973. The results are summarized annually and only the state soil testing laboratory is identified. Consistently the University lab has recommended the least expensive fertilizer program and has produced the same yields. Since many laboratories recommendations have certain identifying traits, most knowledgeable farm advisors and fertilizer dealers soon learn how the lab they use rates in this program. Thus a definite quality control function is served. The results from this program are used throughout the Corn Belt and similar programs are currently being initiated in other states.

A second approach is being taken in Indiana. Here, use of a state wide extension computer network, the FACTS system, to take the state lab recommendations to farmers is being developed. This program should be operable by November of 1980. This will allow farmers to bring their soil test results to the county agricultural agents office and, utilizing the local computer terminal, get the University fertilizer recommendations irregardless of soil testing lab used. In this way a farmer who utilizes a commercial soil testing lab, and about 85% of the samples are analyzed by commercial labs, can get a second opinion on his fertilizer recommendations.

Hopefully through these two programs the precision of fertilizer recommendations can be improved. This has been one new role of the State Agricultural Extension Services in recent years to work with the people making fertilizer recommendations and assist them with needed training programs.

In summary, research has given us the basic principles of how fertilizers react in the soil-plant system. We have utilized this knowledge to develop practical tools to base fertilizer recommendations on. While not perfect, and in constant need of updating, soil and plant analysis allow us to adequately maintain our soil fertility and soil productivity.

The main weakness in our knowledge is that while understanding general principles, the quantitative aspects, particularly in relation to environmental effects, lack desired precision. Only through additional research will this precision be attained.

THE CONSEQUENCES OF INADEQUATE DATA OR ANALYSIS

There are three main areas in which inadequate data or analysis relating to fertilizer use can have effect. These are the areas of public policy, farmer profitability, and finally long term effects on society as a whole.

In the area of public policy every effort must be made to carefully analyze situations relating to fertilizer use before decisions are made. American Agriculture today depends on fertilizer, particularly nitrogen fertilizer and any policy which would limit the supply of nitrogen, could have effects on feed grain production. While the effects would not be as immediate the same can be said for decisions which would limit supplies of phosphorus and potassium. Also real research needs exist which require funding on a continuing basis. Research in soil testing and plant analysis technique and calibration, and basic soil and fertilizer chemistry as well as work on potential environmental consequences of fertilizer use are needed. While these programs are not flashy, they provide a definite service to the American public.

In the area of effects on farmers the real problems relate to developing educational programs to better inform farmers of the tools available to them which can allow them to more efficiently utilize their resources. While soil testing is used today, considerable improvement in sampling technique and frequency, the use of plant analysis and other fertilizer related programs is needed. The cooperative extension service can and must play an active role here.

Finally the effects on society are mainly in two areas. First the effects on environmental quality, particularly water quality, and second on resource relocation. Efforts must be made to be certain no harmful effects on the environment occur, but also cost/benefits must be weighed since fertilizer use today is essential to adequate production of food and fiber. Also efforts must be made to see that fertilizers are used efficiently since they do represent major expenditures of national resources which have alternative uses.

In summary, care must be exercised to guarantee that adequate fertilizer supplies are available to maintain our agricultural productivity. But also help must be available in the form of research and education to see that these national resources are used efficiently and in a way which will minimize effects on the environment.

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Background Paper No. 24

THE DATA BASE FOR ASSESSMENT OF THE IMPACTS OF TECHNOLOGIES ON PRODUCTIVITY OF RANGELAND RESOURCES

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Abstract

1. Rangeland distribution and vegetation characteristics. Approximately 70 percent of the nation's ranges lie in the 17 western states of which about 52 percent is found in the 11 western states and the remaining 18 percent in the Great Plains states. Broad vegetation types can best be used to classify range types throughout the United States but smaller more homogeneous ecological units are needed for management purposes. The vegetation ecosystems vary widely on rangelands. They include grasslands or prairie types, desert shrubs, chaparral, and understory herbage in both coniferous and hardwood forests in various parts of the U.S.

2. Description and evaluation of rangeland data bases. There are no known data sets of any substantial size that would allow range scientists to access information that would cover anything but very narrow subject matter; large data banks are being developed. Land managers, likewise, have no readily accessible large data base needed to manage rangelands. Considerable confusion still exists over rangeland classification terminology. Data bases for policy makers have been developed in response to legislation and provisions have been made to update and improve these decision-aiding data bases.

3. State-of-the-art in rangeland information storage and retrieval systems and computer procedures for analyzing resource management problems. The management of biological systems is a complex problem because of the mere dynamics of the system and the hundreds of interactions and processes that are influenced by virtually thousands of variables. Many site specific computer programs have been developed but fail when applied to different sites where model parameters are unknown. Judgment is required to carefully interpret model output. Serious limitations in making the necessary assump-

tions to run these models make them somewhat less than satisfactory for range management planning.

4. Impacts of government policies on intrinsic productivity of rangelands. Public Land Law Review Commission studies in 1970 convinced Congress that the rules and regulations governing public land use were inadequate. As a result the Commission proposed one hundred thirty-seven specific recommendations. Many legislative acts confound administrative legality of rangeland problems between state and national authority. It is believed by most land managers that a new evaluation and periodic adjustment between environmental quality and land use will be necessary. Impact statements are thought of as safeguards but have proven costly and counter productive in many cases. Many of our recent legislative enactments really created more issues because of vagueness of the bill, delegation of authority in the bill, the addition of amendments or irrelevant riders, differences between the bill and the intent of Congress, and regulations that interpret the administration of the legislation.

5. Breadth of the data base and its analysis. The size and depth of the energy and mineral resources data base is likely of greater detail and depth than the data base of all other rangeland resources combined. Timber resource data bases are relatively detailed. The depth and detail of the wildlife data base is severely limited but three recent efforts to improve this data base have made significant progress. There is a seriously meager rangeland watershed dynamics data base. Data bases on riparian and aquatic environments are in their formative stages. No organized cultural resource data base has been identified.

6. Data collection and analysis, new or emerging methods. Modeling efforts are limited by lack of specific resource information. More cost-

effective multiresource survey and inventory procedures are being conceptualized and great potential exists. Multistaged sampling of rangeland resources and gradient analysis procedures appear to help with spatial complexity problems in rangeland resource inventories. Efficient allocation of the labor intensive ground component of multistaged inventory will likely pay the greatest dividends in resource inventory for the short and long-term future.

7. Consequences of data and analysis inadequacies. Erroneous decisions are likely because management models are being run with extrapolated data sets. Much inappropriate data is applied by range managers because their academic training in this field is inadequate. Lack of data often times leads to no management at all and deterioration of the resource, or it may lead to non-use and loss to society.

8. Priorities for expansion of existing or creation of new data collection or analysis programs. The greatest need is to complete and make accessible, information bases that have already been started but never completed because of personnel turnover and other factors. Resource managers need to develop data bases while interacting with other resource disciplines; the result would be a more widely used data base.

THE DATA BASE FOR ASSESSMENT OF THE IMPACTS OF TECHNOLOGIES ON PRODUCTIVITY OF RANGELAND RESOURCES

Introduction

There are approximately 1.2 million acres of rangeland in the United States. This is about 63 percent of the total land area and most of it is still privately owned (Table 1). Many of the ranges in the United States are used as an integrated part of a grazing-feeding system that includes crop lands and their produce either as grain, forage or crop aftermath. Most livestock operations of the 11 western states are dependent on federal grazing to a significant degree because of the dependence of these lands for seasonal feed supplies that would otherwise be lacking.

It is generally believed that rangeland resources are not being managed or used at their full potential. This is largely a result of a lack of the application of intensive management techniques and economic constraints brought about by inflationary investments or evaluations of land along with rather rapid fluctuations in animal numbers.

Because of the relatively low production of rangelands compared to crop lands and many forest lands, the priorities for improvement, research and more intensive management has not favored them. Since it is becoming more evident each day that cultural or subsidized energy inputs, to a large degree, influence the price of food to the consumer, more emphasis will have to be placed upon the use and management of our rather large acreage of rangeland. In order to minimize cultural energy input and ultimate cost of red meat, rangelands must be used more effectively in order to make a substantial contribution to lowering the price of meat protein at the market place.

Table 1. Area (1000's of acres) and ownership (%) of rangeland in the United States.*

Ownership	Area	Percent
1. USDA-Forest Service	166,902	13.8
2. Bureau of Land Management (Natural Resource Lands)	174,441	14.5
3. Other Federal	44,892	3.7
4. Non-Federal	820,554	68.0
Total, Forest-Range	1,206,790**	100.0

* Taken from FRODAS Preliminary Report (Appendix item 40).

** Total may not equal sum of parts, because of rounding.

The goals and objectives of the immediate future should be to obtain more effective multiple-use of our rangelands through the exploration of new technologies and the application of those that are currently known.

Of great importance to improving the intrinsic productivity of rangelands through better application of technology would be by means of developing a better data or information base where retrievable knowledge could be readily obtained through a rather simple computerized search procedure that would access all available information sources. Such a system would reveal deficiencies or voids of needed information that could be complemented through additional research or by rapid and current updating of the system.

Rangeland Distribution and Vegetation Characteristics

Approximately 70 percent of the nation's rangelands lie in the 17 western states of which about 52 percent is found in the 11 western public land states and the remaining 18 percent in the Great Plains states. The various broad range types found within the western states consist of grassland types including the tall and short grass areas of the Great Plains, the desert grass types of the southwest, the bunchgrass types of the northwest and the Pacific coast, and the annual grassland of California, the coniferous forest understory, the pinyon-juniper, the chaparral, the mountain shrub types of the intermountain areas of the west, and the desert shrub types of the southwest and in the Great Basin area.

The grazing or rangeland vegetation types of the southeast have been classed as upland and lowland hardwoods, loblolly-shortleaf pine, longleaf-slash pine, oak-pine and oak-hickory. Likewise the northeast has several vegetation types, many of which are grazed wooded rough country and wetlands unsuited for cultivation.

These broad vegetation types have been further divided by many agencies and scientists into sub-vegetation ecosystems. Most plant material inventory systems follow these smaller, better defined vegetation units and the data base systems follow one or a modified form of some, more or less, homogeneous plant-soil ecological units.

Description and Evaluation of Rangeland Data Bases

(a) Range scientists and their need to analyze ecological processes: There are no known data sets of any substantial size that would allow the scientist to access information that would cover anything but very narrow subject matter. Even these areas would be limited in period covered and descriptors used. The range scientist compared to the chemist, the economist, the engineer or even other agricultural scientists has only a modicum of accessable data based on almost any subject matter field in his discipline or expertise.

It should, however, be mentioned that many data banks are being developed that may in time be useful to the range scientist, but to date these are few and are rather slow in their progress toward a worthwhile contribution to range science.

Many of the scientific data bank programs are oriented toward assembling information for simulation models of ecosystem processes. In other cases, information is being assembled to model subsystems of the functions and interactions of the various components of rangeland ecosystems. This developmental activity appears to be progressing very slowly at the present time compared to the rather active programs that were associated with the advent of the International Biological Programs that flourished from 1967 to 1977. See section on "Identified Data Bases" in the Appendix for an example of an ecosystem process data base (1) and computerized scientific literature data bases (2 through 13).

Of particular interest to range science and management are the U.S. Department of Agriculture, Scientific Education Administration stations, centers and laboratories, and the Forest Service experimental ranges (see items 49 and 50 in Appendix). Only through long-term research and study in important representative range ecosystems of the United States can adequate information be obtained. Many of these facilities have extremely valuable long-term data sets dating back to the early part of this century. During the last five years many of the scientists at these facilities have retired after their tenure following the extensive hiring that took place after World War II. New range scientists need to be employed to keep these invaluable data bases current. Certainly these retirements or neglect should not be viewed as problems for the U.S. Department of Agriculture but opportunities to re-focus range research on current rangeland management problems.

(b) Land managers and their need to make pragmatic decisions: Again it should be stated that the formulation of an accessible data base for rangeland managers is for all intent and purposes absent or almost lacking. Although several efforts have been started, few are far enough along in their development to be of substantial aid to the rangeland manager. Federal land management agencies and cooperative extension services should, however, be complimented for recognizing the need for a computerized data base that stores information useful to the land manager for multi-resource use planning. The field manager in his day to day planning, needs more than a documented year to year resource inventory base. He needs to be able to access information on plant and animal responses to environmental stress and their interactions by season and physiological functions being performed by each, respectively. They need information on normal plant and animal population dynamics as influenced by management techniques. He or she needs information on soil-plant relations and thence the soil-plant-animal relations for management of various range sites or phytoedaphic response units. And most of all the appropriate amalgamation of the resource uses to be accommodated.

Ranchers especially need economic information including land, labor and livestock market data. In addition they have ready access to human data or information bases through Cooperative Extension farm and home advisers through land-grant institutions, and through U.S. Department of Agriculture, Soil Conservation Service range and livestock specialists. Rangeland productivity has been markedly increased by such advisers recommendations on choice of livestock, animal husbandy practices, grazing systems development, plans for erosion control and range improvement practices. Data bases for both public and private resource managers are given in Appendix items 14 through 38.

Considerable confusion for both range scientists and managers has been caused by proliferation of rangeland classification terminology. The Society for Range Management has formed a Range Inventory Standardization Committee (RISC) to help develop and recommend (1) terminology for inventory, classification and analysis; (2) a uniform system for classification and mapping; minimum standards and guides for data collection; and (4) a common philosophical base for interpretations.

Five range classification schemes have been used and five different terms have been applied: range type, range site, ecological response unit, habitat type, and capability area. The RISC committee recommends that the last four terms listed are or should be used interchangeably. Each represents, or should represent, the basic taxonomic unit in a system of land classification. As such they present a high degree of uniformity with respect to factors which determine potential vegetation and response to management. Range type is an old term referring to 18 "standard" range vegetation types recognized by a 1937 Task Force, and the RISC committee does not advocate their use today. The specific definitions of each term are available in RISC (1980).

Vegetation classification serves to facilitate the recording of information to assist land managers in storage and retrieval of data concerning land management or revegetation characteristics as they vary from one area or region to another. Natural or near natural communities still serve as a standard for comparison. The most predominate basis for comparison is the climax stage which assumes vegetation to be in equilibrium with the climatic characteristics of the area.

As described by Clements (1936) the climatic factors determine the dominant species that will inhabit an area. While this monoclimax hypothesis views the climax as permanent, it is viewed as a dynamic community. The polyclimax hypothesis postulates that a climax expression consists of a mosaic of edaphic, topographic or ecoclimatically different communities with one of the three being geographically dominant (Mueller-Dombois and Ellenberg 1974). Thus the polyclimax recognizes smaller plant expression areas as influenced by edaphic, topographic and microclimatic influences. These two hypotheses differ only slightly in final interpretation of plant communities.

When the stable plant community concept is used to classify vegetation communities, it appears that some form of phytoedaphic parameters must be used. Thus the range site or ecological response units, as a means of recognizing land areas as practical management units, appears useful in evaluating intrinsic productivity of rangelands. The monoclimax and polyclimax theories of classification are adequate in classification of vegetation into plant expression units and standards for ultimate plant succession, but for management of rangeland ecosystems, they are much too broad and do not include edaphic and topographic features to the extent that rather large homogeneous management units are identified.

The range site or the ecological response unit is by definition a homogenous land unit that will respond about the same to management, land treatment or ecosystem manipulation, and it should be used as the basic unit for rangeland classification. Climax theories are sound but subdivisions identified by soil and topography are necessary for intensive planning and management to assure export of goods and services on a sustained basis.

(c) Policy makers need for data bases to formulate effective programs: Policy makers and their role in program formulation depends to a large extent upon public opinion which is dynamic and changes from year to year depending upon the driving forces of demand and economic impact upon the people, both local and national. The formulation of programs that consider the intrinsic productivity of rangeland resources must be dependent upon current inventories and their capability to meet the needs or public demands. Such inventory information should be readily accessible and amenable to computerized outputs that answer such questions as tradeoffs among resource uses and management alternatives. Such information should be available at least in a gross computation for analysis and consideration.

Such a program for rangelands was first formulated by the U.S. Forest Service by a program called FRES (Appendix 39) and later updated by a program in 1980 currently called FRODAS (Appendix 40) and the National Interregional Multiresource Use Model, NIMRUM (Appendix 41).

Three land-based information data bases are ongoing in their development at this time and collectively they constitute the most important rangeland data base for policy makers. First, the U.S. Forest Service will by directive from the Forest and Rangeland Renewable Resources Planning Act of 1974 (Public Law 93-378) as amended by the National Forest Management Act of 1976 (Public Law 94-588), on a recurring basis, refine the inventories (RPA inventory) of supplies and demands on resources for all rangelands on a regional basis (Appendix 42, 43 and 44). The emphasis of this Forest Service inventory is on federal lands, but all rangelands will be inventoried.

Second, the U.S. Soil Conservation Service will by directive from the Soil and Water Conservation Act of 1977 (Public Law 95-192), on a recurring basis, refine the inventories (RCA inventory) of the status and condition of our soil, water, and related resources (Appendix 14, 15, 16 and 45). The emphasis here will be on privately owned rangelands, but all rangelands will be appraised.

Third, and finally, due to the Natural Resources Defense Council's lawsuit in October 1973 and court action in its favor on December 30, 1974, the U.S. Department of Interior, Bureau of Land Management is conducting selected allotment specific inventories (approximately 200) on all the BLM-National Resource Lands (174 plus million acres). Through this environmental impact statement process valuable use and resource related inventory data bases are being developed (Appendix 19, 20, and 21). In the process of doing this job, BLM has funded, through the National Academy of Sciences, six symposia/workshops to get aid for this effort and other rangeland management tasks. The proceedings from these six symposia/workshops covering vegetation allocation, rangeland inventory, socioeconomic considerations, management of livestock grazing on wetland and riparian areas, grazing systems, and range improvements, will constitute a valuable rangeland information base.

Data bases developed especially for policy makers are given in Appendix items 39 through 45.

State-of-the-Art in Rangeland Data Storage and Retrieval Systems and Computer Procedures for Analyzing Resource Management Problems

The management of biological systems is a complex problem because of the mere dynamics of the system and the hundreds of interactions and processes that are influenced by virtually thousands of variables. Thus even the simplest sub-function model would at best be a computerized estimation of an organized thought process that might be available to the rangeland manager in a matter of seconds if the model were accessible.

Many computer programs are developed for a particular purpose, for a particular area, and for a particular ecosystem. After many, many trials such efforts are found to run satisfactorily. However, when these models are taken to other regions the parameter values are not known in some cases and guesses make the resource solution rather uncertain, but it may be better than simple deductive reasoning.

Several computer models have been developed to determine the impacts of manipulation of the system as it affects populations or normal functions.

In some cases the model is so complicated that the output, unless adjusted for reason, can be very misleading. Also managing for maximizing a product can be rather simplistic and straightforward, but managing for optimum levels of numerous products is complex.

It is safe to state that the land manager, except in a few cases, does not generally have available land resource management models and, in most cases, would not understand their parameter values or their outputs if he did.

The most widely used management models are in wildlife management with the predator-prey relationships and the population dynamics prediction models along with land resource allocation models. Large scale management systems models are being explored but practical application where all causal and feedback linkages are known and understood are not available to the rangeland manager at the field level. Such systems when developed for use should provide appropriate display schemes in order to facilitate land planning methods to accomplish the objectives that are consistent with sustained productivity of the land resources.

Using shortgrass prairie grazinglands data Van Dyne et al. (1977) demonstrated the practical use of simulation and optimization models for synthesis, integration, hypothesis testing, impact analysis, and management decision making. Some major difficulties in using simulation models in the resource management decision-making process were described, and included such items as large data input requirements (initial conditions, driving variables, and site constants), and lack of spatial components (most models to date are point models that cannot simulate spatial situations, therefore coupling of management units is not possible).

Various econometric models have helped private range managers with allocation of alternative feeds. These models have been, for the most part, limited to cattle feedlot feeding and least-cost ration formulation. Recent research on ranch level linear programming and resource allocation models by researchers at Colorado State University (COPLAN and GOAL) (Bartlett, Evans and Bement 1972; Jameson and Child 1972, Bottoms 1974, Bartlett, Evans and Bement 1974, Evans 1974, Bottoms and Bartlett 1975, Bartlett, Bottoms and Pope 1976) and USDA Forest Service, Pacific Southwest Forest and Range Experiment Station (Range RAM) (Jansen 1975a,b,c and 1976) have developed practical decision-aiding models. These models have been tested using actual ranch and grazing allotment examples but serious limitations in making the necessary assumptions to run these models make them somewhat less than satisfactory for range management planning. Like simulation models, these models require extensive data that are frequently not available for the ranch or allotment. Interest in these models has dwindled in the last few years. None of the land use allocation models have been put into operation on rangelands.

Impacts of Government Policies on Intrinsic Productivity of Rangelands

The data base on how government policies and programs affect the productivity of rangeland resources is diffuse, confused, and often value-judgment dependent. The best, although seriously out-of-date, data base is the Public Land Law Review Commission's report to the President and the Congress of the United States (1970). The Commission examined each and every public land law as well as the regulations, practices and procedures involved in their administration. One hundred thirty-seven specific recommendations were proposed.

The Commission's studies convinced Congress that the rules and regulations governing public land use were inadequate; that these rules and regulations were promulgated without proper consultation with those affected or the general public; that existing regulations were cumbersome; and that the procedures for users or other interested parties to exercise their right to oppose newly proposed rules and regulations were unwieldy, expensive, and without assurance of objective and impartial consideration.

The Commission recommended that statutory goals and objectives should be established as guidelines for federal-land use planning under the general principle that within a specific unit, consideration should be given to all possible uses and the maximum number of compatible uses permitted. Where a unit, within an area managed for many uses, can contribute maximum benefit through one particular use, that use should be recognized as the dominant use, and the land should be managed to avoid interference with fulfillment of such dominant use.

The Commission found it useful to aggregate the general public into six categories of identifiable interests to make its decisions. The categories were:

1) the national public

2) the regional public

3) the Federal Government as sovereign

4) the Federal Government as proprietor

5) state and local government

6) the users of public lands and resources

It felt that this approach assured maximum benefit for the general public.

Chapters 3 (Planning Future Public Land Use), 4 (Public Land Policy and the Environment), and 6 (Range Resources) contain the most germain recommendations for analysis. The proliferation of new laws since the publication of the Commission's report shows that many of the recommendations were implemented. The question remains to be answered whether the laws enacted have actually resulted in a net benefit to the general public.

Three widely discussed laws, for example, can be shown to have reduced livestock productivity of rangelands. The bans on uses of the herbicides 2,4,5-T and predator toxicants on public lands have reduced the options available to range managers to increase herbaceous plant production and reduce predator-caused losses, respectively. Restrictions imposed on range improvement options in designated wilderness areas likewise has reduced livestock productivity. The difficult task ahead is to determine whether the net flow of rangeland resources to the general public has increased or decreased. No objective means of analysis now exists to answer this question.

Impact statements and injunctions are frequently delaying tactics used by parties on both or all sides of an issue that delay or infringe upon management alternatives. These are thought of as safeguards for environmental safety of the people but have proven costly and counter productive in many cases as it concerns managing rangelands for their natural potential to produce renewable resource materials for the benefit of mankind.

Many legislative acts confound the administrative legality of rangeland problems between state and national authority. Rather than coordinating state and federal authority they appear to disperse it. Such is the case in water, minerals, environmental thresholds, etc., which, to a large degree, is responsible for the "sagebrush rebellion" in western lands. It is recognized that one-third of all lands in the U.S. consists of federally owned lands but their uses are entangled with the uses of private lands that support various land resource enterprises. As a result consideration should be made for the local importance of the integrated uses of private and federal lands because it may severely affect the welfare of entire communities.

It is believed by most land managers that a new evaluation and periodic adjustment between environmental quality and land use will be necessary. Furthermore both regulatory and land use planning agencies at all levels of government should have input into the acceptable and reasonable levels of environmental infringements from different land use strategies. The environmental-land use issues are multidimensional and as a result are complex and present multifaceted problems. These land use problems relate to the economic, physical and social interactions that do not fit a land use guide for solutions at any level of government or by any one regulatory agency. It can be safely stated that many of our recent legislative enactments that were supposedly passed to resolve a land use issue really created more issues because of vagueness of the bill, delegation of authority in the bill, the addition of amendments or irrelevant riders, differences between the bill and the intent of Congress in the hearings, and lastly, the regulations that interpret the administration of the legislation.

List of Recent Important Acts that Especially Affect Rangelands:

Forest and Rangeland Renewable Resources Planning Act of 1974.
Public Law 93-378.

Federal Land Policy and Management Act of 1976. Public Law 94-579.

The National Forest Management Act of 1976. Public Law 94-588.

Soil and Water Resources Conservation Act of 1977. Public Law 95-192.

Forest and Rangeland Renewable Resources Research Act of 1978. Public Law 95-307.

Renewable Resources Extension Act of 1978. Public Law 95-306.

Breadth of the Data Base and Its Analysis

Given the inadequacies of the rangeland data base with respect to vegetation condition and productivity, soil capability and erosion hazard which relate directly to livestock carrying capacity determinations, clearly the depth of the data base in areas of wildlife, watershed dynamics, riparian and aquatic environments, cultural resources, energy and mineral resources, wood and other plant resources is, in most instances, very superficial or even non-existent on many rangelands. It might be of help, however, to assess their breadth in ranked order and discuss some important programs that are actively developing these breadth areas.

The following is an estimate of the ranked order of data base depth and breadth from greatest to least:

1. Energy and mineral resources
2. Wood and other plant resources
3. Wildlife
4. Watershed dynamics
5. Riparian and aquatic environment
6. Cultural resources

Collectively, private corporations certainly have the largest data base on energy and mineral resources on rangelands including especially oil, gas, coal, oil shale, and hard rock minerals. Two data and information bases (Appendix 9 and 46) are especially useful to land managers in their efforts to maintain or restore lands disturbed by energy or mineral extraction. The size and depth of this data base, both for resource supply inventory and rehabilitation is likely of greater detail and depth than the data base of all other rangeland resources combined.

Because of the extensive data base on timber resources, especially on forest-rangelands of National Forests, the wood and other plant resources data base probably ranks second in depth and detail. Regional forest survey inventories have been conducted for many years and have now been put together in one location for the Resources Planning Act (RPA) data base (Appendix 43). The accuracy of this data base varies widely and is probably a function of how recent the last revision was made in a particular inventory.

Recent renewed interest in alternative energy sources has focused attention on promising desert crops such as guayule, jojoba, mesquite, and caper spurge. To a large extent these resources are at the experimental level at this time and data bases concerning agronomic practices for economic production of these crops appears to be the limiting factor.

The depth and detail of the wildlife data base is severely limited. Extensive literature exists for game species, especially deer, elk, antelope and upland game birds, but non-game wildlife information is very limited and usually includes only minimal natural history information. State fish and game agencies and the U.S. Fish and Wildlife Service are the basic sources of wildlife data. Again, the RPA wildlife data base (Appendix 44) is the most extensive compilation on wildlife species.

Three major efforts have made some significant progress in expanding and compiling more detailed wildlife data bases (Appendix 22 and 24, Thomas 1979, Thomas and Maser 1979). These efforts have led to a new systematic approach to habitat analysis including a featured wildlife species approach relating habitat requirements specifically for reproduction and feeding. Given the need to allocate food, water and space to wildlife and livestock on rangelands, considerable knowledge about wildlife requirements is needed.

No organized data base pertaining to watershed dynamics of sediments, dissolved constituents, particulates, and water in a watershed framework were identified. Some rangeland watershed research centers were identified (Appendix 49). The most unifying attempt to model rangeland soil erosion and determine soil erosion hazard has been proposed by application of the universal soil loss equation to rangelands (Weishmeier and Smith 1978). Many researchers are now testing the power of prediction of this equation. No acceptable procedure has been developed to separate estimated natural from man-caused erosion. Establishment of acceptable erosion rates is impossible until soil formation rates are known. The USDA Soil Conservation Service data base on soils and range sites (Appendix 14 and 15) contain estimates of erosion hazard for many soils.

Data bases on riparian and aquatic environments for rangelands are in their formative stages with basic projects on classification of riparian and wetland systems just beginning (Thomas and Maser 1979). No economically feasible alternatives have been proposed to eliminate livestock grazing impacts on riparian systems. The bulk of the current research is still emphasizing documentation of impacts, not testing alternative solutions using different grazing systems.

No organized data base on cultural resources was identified. Cultural values have been designated at the highest level resulting in requirements for archaeological clearance for all range management improvement projects.

All land management agencies and state archaeological staff regulate inventory and classification of significant sites on rangelands. Procedures for surveys and designation of sites appear to be well developed and sufficient to protect the resource, the only apparent limitations are funds and personnel.

Data Collection and Analysis,
New or Emerging Methods

More and more models are being developed to simulate functions and processes of the ecosystem. These not only help understand the interactions, driving forces, linkage feedbacks, and response lags but also aid in management decisions.

Many linear program models that are being developed for resource allocation and overall management plans are dependent upon rather detailed and specific resource information that are not available. Such information is currently being gathered by land management agencies, but the efforts at best still receive low priority and in many cases are not correctly identified or characterized for simulation or decision models.

Interdisciplinary efforts are being proposed to integrate or link different land resource bases so that the information is accessible by one complete program instead of several. Multiresource surveys and inventory procedures are being conceptualized and there appears to be great potential for increasing efficiency of surveys and correlating interactions among resources and uses when such surveys are used. Computer assisted methods now exist to overlay polygons or grids of information allowing land use planning teams of resource specialists to use their judgments in evaluating tradeoffs for alternative management programs.

Two new and emerging methods of data collection and analysis bear adequate promise. Multistaged sampling of rangeland resources with Landsat imagery, one or more scales of aerial photography, and conventional ground sampling shows the greatest promise to get adequate inventory vegetation cover data on extensive rangelands (Aldrich 1979). Coupling of these procedures with gradient modeling and analysis of spatial resource relationships appears on the horizon as a new practical resource analysis procedure (Kessell 1979). Both procedures have been tested on a small scale and need to be modified and improved for large scale applications. Prospects for increased efficiency in computer storage capacity and computation speed makes such methodology more feasible for the immediate future.

No breakthroughs are expected for ground sampling and ground inventory methodology. Efficient allocation of the labor intensive ground component of a multistaged inventory will likely pay the greatest dividends in resource inventory for the short and long-term future.

Consequences of Data and Analysis Inadequacies

It is comparatively simple to assess the worth of data or information that results in more effective management along with increased productivity of exportable material from rangeland ecosystems, but to evaluate the consequences of data or information that are believed to be inadequate is extremely difficult.

Most management models are lacking adequate data for effective use by the range managers. Actual or predictive responses to ecosystem manipulation are not available for all range sites and as a result management models will reveal a totally erroneous decision because the output is not applicable.

Much inappropriate data is applied by range managers because their academic training in this field is inadequate. Almost 50 percent of the Range Conservationists today have only 6 to 12 semester college credits in Range Science. As a result data, its analysis and application are frequently used where they do not really apply and as a result intrinsic productivity is affected. Well trained range scientists know where data and ecological principles apply, whereas poorly trained range scientists have a tendency to use a rule-of-thumb application of information and as a result apply ecological principles in many situations that are not appropriate.

A lack of data and its analysis for managing various ecosystems often times leads to no management at all and to deterioration of the resource. It may actually lead to non-use of the resource which can be a real loss to the American people. This is particularly true of renewable rangeland resources that are left unused because of incompetent expertise.

Priorities for Expansion of Existing or Creation of New Data Collection or Analysis Programs

It appears that the greatest need in data collection and analysis programs is to complete and make accessible, information bases that have already been started but never completed because of personnel turnover and other factors. Many cases of this nature could be cited for all of the federal land managing agencies and for both state and federal research institutions. The data base collections for special interest groups seem to get most of the attention and financial support while new and worthwhile projects are neglected.

Many data base collections are carried out by only a few individuals or even only one for the simple purpose of satisfying the queries of a select few. For a program to receive adequate support it must be useable to national program decision or policy makers. Much data base material is shipped from office to office and becomes almost an unknown in a computer storage system without identity or purpose.

Of great concern is the computer programmer trying to store, retrieve, analyze and explain data base material without the aid of the resource managers. Also of great concern is the resource managers that collect data and develop programs without interacting with other resource discipline areas. These isolated efforts are many and diffused in all land management agencies. As a result many data banks serve only a relatively small segment of either the range managers or the policy makers.

Many people are in charge of data bank material but are not expert in how to access it or aggregate it for use outside the computer interpretation. This is also true of data base information that supposedly is available at major libraries. Identifying words and phrases in an appropriate sequence is essential in searching data base information material. Training in the procedure and the resource field are essential in data base information searches if the cost is to be reasonable.

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APPENDIX

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Ecosystem Processes

1. Example of International Biological Program (IBP) Information and Data Base for the Grassland Biome

Six biome and ecosystem studies in the International Biological Program developed data bases in the late 1960's and 1970's that are valuable for the bio-physical parameters they estimate and the ecological processes they help to describe. These rangeland related studies are: grassland, desert, tundra, coniferous forest, deciduous forest, and Mediterranean shrub studies. Sources of information and data bases for all six are given below. A brief description of the IBP-Grassland Biome information and data base is given as an example. Similar kinds of information, data bases, and models are available for the other five studies.

Grassland ecosystem data bases from seasonal monotoring of producers (aboveground herbage, belowground herbage, litter, phenology and decomposition), invertebrate studies (aboveground and belowground biomass and density), bird studies (counts, diets, and nesting activity), small mammal studies (populations, diets, and energetics), large mammal studies (cattle growth and diets of cattle, bison and antelope), abiotic weather and soil moisture measurements, chemical composition analyses of producers, soil analyses, and insect and small mammal diet analyses.

Ecosystems level models of the shortgrass prarie (PAWNEE and ELM) and other grasslands were produced. Numerous sub-ecosystem models were also produced. Study sites included the primary Pawnee site at Nunn, Colorado and supporting sites named Dickinson, Bridger, Pantex, Cottonwood, Hays, Jornada, Ale, San Joaquin, and Osage.

Summary means and variances for most data sets are available and useful mainly for range scientists. More than 226 reprints are available in the literature or from the Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO 80523.

Contacts for other biome information and data bases are as follows:

Desert Biome
Dr. Frederic H. Wagner
Ecology Center
Utah State University
Logan, UT 84322

Tundra Biome
Dr. Jerry Brown
Earth Sciences Branch
U.S. Army
Cold Regions Research and Engineering Laboratory
P.O. Box 282
Hanover, NH 03755

Coniferous Forest Biome
Dr. Stanley P. Gessel
School of Forestry
University of Washington
Seattle, Washington 98105

Deciduous Forest Biome
Dr. Stanley I. Auerbach, Director
Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Mediterranean Shrub Study
Dr. Phillip C. Miller
Systems Ecology
San Diego State University
San Diego, CA

Computerized Literature and Information

2. Bibliography on Ranges, Pastures, Wildlife, Livestock and Ranching

This material is presented in published text form under the authorship of John F. Vallentine by the Oryx Press 1978 and covers all facets of managing rangelands in the United States. Subject matter material can be accessed through an automated computer search by Systems Development Corporation which includes this reference information. The coverage includes forage and poisonous range plants, ecological and physiological principles used in management of rangelands, utilization and management systems of rangelands, range improvement methods, range livestock husbandry and ranch planning. The treatis includes contents of the Journal of Range Management and Rangeman's Journal (now Rangelands) and selected material from 1935-1977 from all other journals related to management and use of rangelands.

A wealth of such information is indeed useful not only to the biological scientists but to the rangeland managers and decision makers as well.

Available from ORYX Press, 3930 E. Camelback Road, Phoenix, Arizona 85018 or Systems Development Corporation, at most large libraries.

3. Agriculture on Line Access (AGRICOLA)

Cataloging and indexing data base of the National Agricultural Library with comprehensive coverage of journal and monographic literature on agriculture and related subjects. 1970-present, 1,340,000 records, monthly updates. Useful to scientists, land managers and policy makers.

Computer searches available for a charge in most large libraries. Maintained at the National Agriculture Library, Beltsville, MD.

4. National Technical Information Service (NTIS)

Computerized data base of government-sponsored research, development and engineering plus analyses prepared by federal agencies, their contractors or grantees, including NASA, DDC, DOE, HEW, HUD, DOT, Dept. of Commerce, and some 240 other units. State and local governments are now beginning to contribute their reports to the file. 1964-present, 765,000 citations, biweekly updates. Useful to scientists, land managers and policy makers. Maintained by NTIS, U.S. Dept. of Commerce, Springfield, VA.

5. Biosciences Information Service (BIOSIS)

Contains citations from both Biological Abstracts and Herbage Abstracts. Nearly 8,000 jurnals as well as symposia, reviews, preliminary reports, semi-popular journals, selected institutional and government reports, and research communications on all aspects of the biosciences and medical research. 1969-present, 2,600,000 records, monthly updates.

Useful to scientists, land managers and policy makers. Computer searches available for a charge in most large libraries. Maintained by Biosciences Information Service, Philadelphia, PA.

6. Commonwealth Agriculture Bureaux Abstracts (CAB)

Computerized comprehensive file of agricultural and biological information containing all records in the 26 main journals published by the Commonwealth Agricultural Bureaus. Over 8,500 journals in 37 languages are scanned, as well as books, reports, and other publications. 1973-present, 966,000 records, monthly updates.

Useful mainly to scientists. Maintained at the Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, Slough, SL2 3BN, England.

7. Smithsonian Science Information Exchange (SSIE)

Computerized data base containing reports of both government and privately funded scientific research projects, either currently in progress or initiated and completed during the most recent two years. Encompasses all fields of basic and applied research in life, physical, social, and engineering sciences. Covers last 2 years, 1978-present, 299,000 citations, monthly updates.

Useful mainly to scientists. Maintained by SSIE, Washington, D.C.

8. System Development Corporation (SDC)

Computerized reference base of the Journal of Range Management and the book "U.S.-Canada range management 1935-1977 - a selected bibliography on ranges, pastures, wildlife, livestock and ranching".

A useful data bank for scientists, range managers and decision makers.

Information can be accessed from most major libraries.

9. Surface Environment and Mining Alert to Current Literature (SEAMALERT)

This computerized program is an information and bibliographical record relating to surface mining, reclamation and mineral extraction technology gathered by the U.S. Department of Interior, Office of Surface Mining. The computer data base and retrieval system is known as SEAMINFO. Information is coded by aquatic and terrestrial ecosystems, by states, and by minerals being surface mined. Search words include plants, life forms, habitats, seeding, planting methods, sodium-affected soils, top soils or top soiling, soil erosion, etc.

Such information is important to the reclamation researcher and to the land managers and the decision makers.

SEAMINFO search information is available from Mine Reclamation Center, University of Arizona, 845 N. Park Avenue, Tucson, Arizona 85719.

10. Remote Sensing for Renewable Resource Inventory Literature Data Base

Worldwide coverage of remote sensing, resource information and resource analysis literature, 1200 citations with about 100 citations added per year. Can be retrieved by author, title or keyword.

Useful to resource scientists and managers. Available through U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.

11. Remote Sensing Reference Collection Literature Data Base

Worldwide coverage of techniques, equipment, data analysis, and applications to remote sensing. 1150 citations with 100 citations added per year. Can be retrieved by author or title or keyword only.

Useful especially to resource scientists and managers. Available through U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.

12. Sagebrush in the Western United States Literature Data Base

Computer retrievable liteature on distribution, autecology, synecology, and management of North American sagebrush including 1250 citations from 1900 to 1978 with about 50 citations added per year.

Useful to range scientists and managers. Available for reproduction cost by author only, or author and title searches through U.S. Dept. of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

13. Western Forestry Information Network (WESTFORNET)

A system that provides technical information services through 1) monthly newsletter listing of selected new aquisitions to WESTFORNET libraries at Berkeley, Seattle, Ogden, Logan and Ft. Collins, 2) document delivery, 3) literature searches, and 4) reference services.

Useful to scientists, land managers and policy makers. Available through any of the Forest Service Experiment Stations but centered at Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Resources and Resource Management Data Bases

14. National Resource Inventory (NRI)

Is a computerized data base of plant and soil materials of both range and crop lands of the United States. The first data base information was known as Conservation Needs Inventory (CNI) for 1958 and 1967. This is now known as National Resource Inventory (NRI) and currently has computer storage up to 1977 data. The next projected data base analysis will be in 1982. These data base systems include plant community production by range sites, land capability classes, range condition classes along with erosion susceptibility and acreages by state and land resource areas.

This information is most useful to the decision makers and land use planners but does serve as a data base for scientists interested in simulation and predictive models for determining trends and projected uses of the land resources.

This data is available at Dept. of Agriculture, Soil Conservation Service, Director of Inventory and Monitoring, P.O. Box 2890, Wash. D.C. 20013.

15. Soil Interpretation Records (SIR)--Also known as Soils-5 Data Base

This is a computerized program that serves as a data base for all soil survey information in the United States. The identification level of information is based primarily on the soil series and soil families by state and county level. Information characterized for the soil units are both physical and chemical properties along with land capability classifications and erosion susceptability.

This information is extremely useful for soil and range scientists and land managers. Such knowledge is basic to all land resource uses.

This data base is available from Soil Interpretation Records, Soil Conservation Service Survey Project, Statistical Laboratory, 217 Snedecor Hall, Iowa State University, Ames, Iowa 50011.

16. Production Records/Range Data System (RDS)

This data base is a plant materials data system with over 3,000 entries at present for rangelands of the west and southeastern United States. Most information is identified with range sites, soil series and land capability classes to the state level. Associated information that can be aggregated are production as influenced by climate, elevation and condition class.

This information is to be up on computers by 1985 and will be extremely useful to both range managers and decision makers. It will be available at U.S. Dept. of Agriculture, Soil Conservation Service, South Technical Service Center, P.O. Box 6567, Ft. Worth, Texas.

17. Kuchler Potential Natural Vegetation Map of United States

Map of potential natural vegetation including 107 communities for the coterminous United States. Used by range scientists, range managers, and decision makers as the basis for comparing present vegetaton with expected pristine climax vegetation.

Available in libraries and American Geographical Society, Special Publication #36, New York. 1964.

18. NASA-LANDSAT Data Tapes

Computerized data tapes providing images of the United States every 18 days at a gross level.

Useful to scientists, land managers, and decision makers to stratify and help classify rangelands into categories. Available for a small charge through EROS Data Center, Sioux Falls, SD.

19. Soil Vegetation Inventory Method Data Base (SVIM)

Computerized data bank containing soil, vegetation and supporting resource information on U.S. Dept. of Interior, Bureau of Land Management

(BLM) land in the United States. It contains computer programs to manipulate BLM District and state level multiresource inventory data at various levels of detail, and programs to allocate resources, especially forage, to livestock and wildlife. As grazing environmental impact statements are completed this data bank will grow to include detailed resource inventory, allocation and use data on much of BLM lands.

Information is especially useful to land managers, policy makers and in some cases to range scientists studying long-term productivity of rangeland.

Available at U.S. Dept. of Interior, Bureau of Land Management, Denver Service Center, Building 50, Denver Federal Center, Denver, CO 80225.

20. Job Document Reports (JDR)

Documentation of all U.S. Dept. of Interior, Bureau of Land Management range improvement projects such as roads, fences, wells, and spring developments with improvement descriptions and costs.

Useful to land managers and decision makers in evaluating past range improvement activities. Potentially useful to range economists to evaluate range improvement technology.

Accessible through computers at the U.S. Dept. of Interior, Bureau of Land Management, Denver Service Center, Building 50, Denver Federal Center, Denver, CO 80225.

21. Range Management Automated System (RMAS)

Computerized data base covering all U.S. Dept. of Interior, Bureau of Land Management (BLM) lands and containing the accounting for all public permittee users including: authorized use, licensed use, legal description of the allotment, adjusted potential use, expected use in good and bad production years, trespass records, season of use allowed, and changes in permittees.

Useful mainly to the land management agency BLM. Information available at U.S. Dept. of Interior, Bureau of Land Management, Denver Service Center, Building 50, Denver Federal Center, Denver, CO 80225.

22. Plant Information Network (PIN)

A computer-based data bank for retrieving information on the vascular plants of Colorado, Montana, Wyoming and North Dakota. Information covers species by counties and states, by vegetation ecosystem, and by potential uses of the plant for grazing, wildlife habitat, rehabilitiation or as special indicators of soil chemistry, disturbance, or texture. All plants are classified by life form, family, genus, species, and common name. Currently the data base includes over 4,000 plants.

It seems that the primary users of the information would be plant and animal scientists, and land managers.

Access of PIN can be obtained by writing PIN, Department of Botany and Plant Pathology, Colorado State University, Ft. Collins, CO 80521.

23. National Seed Storage Laboratory Data Bank

Computerized system of storing information on varieties or breeding lines with complete documentation on the history of the breeding or developmental work, its donor, its source and location of germplasm. Material is listed by standard taxonomic divisions along with inventory codes of different types of crops and life forms. The seed source at the laboratory is dispensed only for plant breeding research purposes, but information on species or cultivars is on a data retrievable system that can be accessed. There are currently 113,000 seed or germplasm accessions of agronomic (some range plant), vegetable, and horticulture plants.

Such information is primarily of interest to the plant breeder or land managers that need a plant for a particular purpose such as a legume suited to arid lands with better than average nitrogen fixing capabilities, etc.

Accessibility of information can be obtained through the National Seed Storage Laboratory, U.S. Dept. of Agriculture, Science and Education Administration, Colorado State University, Ft. Collins, Colorado.

24. Run Wild

Computerized wildlife species and vegetation habitat preferences data base by county, habitat, and National Forest for Arizona and New Mexico only. Includes genus, species, common names, general distribution, protection status, vegetation types, food habits, cover requirements, key habitat factors, management practice effects and comments.

Useful for land managers, range scientists and wildlife biologists. Available through U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

Rangeland Economics and Livestock Data Bases

25. Agricultural Computer Network (AGNET)

Computer information and decision aiding service for least-cost ration formulation, analysis of animal performance, crop production budgeting, insect control, irrigation scheduling, fertilizer recommendations, and statistical analysis of data.

Useful to land managers and scientists involved in management decisions. Available via phone connected terminals anywhere, but supported by Cooperative Extension at county level in Nebraska, Montana, North Dakota, South Dakota, and Wyoming.

Contact AGNET, University of Nebraska, Lincoln, NB 68583.

26. Census of Agriculture

Book containing private land inventories by land use categories down to the county level. Inventories livestock at state level on all lands. Gives distribution of farm or ranch sizes. Latest document is dated 1974, new census every 5 years.

Useful to scientists, land managers, and especially policy makers. Maintained by U.S. Dept. of Commerce, Bureau of the Census, Wash. DC.

27. Agricultural Prices (Monthly Publication)

Monthly prices paid and received for all major commodities includes broad averages especially for hay, feed grains, cattle and sheep.

Especially useful for private land managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

28. Livestock and Meat Statistics

Annual document of monthly price summaries at major U.S. markets for cattle, sheep and hogs by weight, grade, and class of animal. Includes imports, exports, and per capita meat consumption.

Useful to land managers and policy makers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

29. State Farm Income Statistics

Annual document of farm income for all agriculture commodities, especially useful for determining relative importance of each commodity (crops and animal). Helpful in determining long term trends.

Useful to scientists and policy makers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

30. Agricultural Statistics

Annual statistics for quantity and production of all agricultural commodities associated with acreages used and prices received. Useful especially for historical time series analysis.

Useful especially to policy makers. Compiled by U.S. Dept. of Agriculture, Wash., DC.

31. Farm Real Estate Market Developments

Bimonthly document used for determining rental rates for grazing fee formulas of land management agencies. Indexed on 1967 prices. Useful for seasonal or monthly rentals and prices for various types of land.

Useful for scientists and especially land managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

32. Senate Agriculture, Nutrition and Forestry Committee Prints

Annual report of costs of producing sheep and cattle (feeder, stocker, cow-calf) in production regions of the United States categorized by size of operation.

Useful to scientists, land managers, and policy makers. Prepared by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

33. Livestock, Meat, Wool Market News

Weekly market prices for major markets in the United States for various livestock products.

Useful to land managers. Compiled by U.S. Dept. of Agriculture, Agricultural Marketing Service, Wash., DC.

34. Cattle, Sheep, Hogs, Goats

January and July data base useful for current year inventories of livestock and predicting market trends.

Useful to private land managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

35. Cotton and Wool Situation

Livestock and Meat Situation (separate documents)

Bimonthly inventory, imports, exports, and prices. Useful to private land managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

36. Range and Pasture Conditions (for each state separately)

Evaluation of current (monthly) range and pasture conditions on a regional basis with forecasts for the near future.

Useful for land managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

37. Feed Situation

Bimonthly evaluation of feed grain production prospects for the near future given current acreages and yield projections.

Useful for land and livestock managers. Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

38. Farm Labor

Useful for all agricultural enterprises for assessing employment problems by seasonal and crop need.

Compiled by U.S. Dept. of Agriculture, Economics and Statistics Services, Wash., DC.

Data Bases for Policy Development

39. Forest-Range Environment Study (FRES)

Computerized data base on forest and rangeland resources in the United States. Lands are segregated into 34 potential plant communities (modified Kuchler system), 3 ownerships (U.S. Forest Service, other Federal, and state and private), productivity classes, and condition classes.

FREPAS: Forest-Range Environmental Production Analytical System is the computer system used to analyze the FRES data for the purpose of evaluating management alternatives and costs of management.

The data analysis was released in published form in 1972. The data base continues to be useful to scientists, land managers, and policy makers.

Available through U.S. Dept. of Agriculture, Forest Service, Data Base Maintenance Group of RET Program, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

40. Forest-Range Output Data Analytic System (FRODAS)

Computerized data base on forest and rangeland resources in the United States. This is a revision of the FRES data base. Lands are segregated into Kuchler's 107 potential natural communities, 4 ownerships (U.S. Forest Service, Bureau of Land Management, other Federal, and state and private), 4 productivity classes, and 4 condition classes. The model can aggregate the land units by state, the 34 FRES ecosystems, or the U.S. Forest Service regions. The data base and FRODAS linear program allows multiresource interaction analysis, cost budgeting for various intensities of management, wildlife benefit predictions, and dispered recreation outputs. Thirteen products are outputed including herbage and browse, net wood growth, wood harvested, domestic livestock, wild ruminants, dispersed recreation, water yield, storm runoff, sediment yield, and plant life forms for habitat evaluation-water, ground, bushes, and trees.

Useful for scientists, land managers and especially policy makers. The data base and programs are available through the U.S. Dept. of Agriculture, Forest Service, Data Base Maintenance Group of RET Program, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

Data tapes will be supplied on request.

Note: the FRODAS report is in preliminary draft form.

41. National Interregional Multiresource Use Model (NIMRUM)

Also called NIMRAS with same name as NIMRUM except Analytic System replaces Use Model. This data base is a linear programming model used to 1) allocate national and regional demands on the land base with minimum cost, 2) evaluate effects of the allocation on regional employment and earnings, 3) account for future options lost, and rate and length of impact on citizens, and 4) assess social conflicts under various alternative allocations. This model uses the same data base as FRODAS.

Useful to scientists, land managers, and especially policy makers. Available through U.S. Dept. of Agriculture, Forest Service,, Data Base Maintenance Group of RET Program, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

42. Resources Planning Act Assessment, Program and Report to Congress 1980 (RPA)

Information documents that describe the present renewable resources situation and projection of future supplies and demands for resources. Fourteen policy statements are set forth to further guide the planning process for future assessments. Five alternative management programs were designed to offer the widest range of technically feasible management options possible within the constraints of applicable laws and policies. A program is recommended for the National Forest System and State and Private Forestry. Enviornmental effects including physical, biological, economic and social effects are assessed.

The information base is available and especially useful to policy makers. Available through U.S. Dept. of Agriculture, Forest Service, Wash., DC. via Supt. of Doc., U.S. Government Printing Office, Wash., DC 20402.

43. Timber 1979 RPA Assessment Data Base

State and regional summaries of growth, yield and stumpage of forest trees on National Forests, other Federal, and state and private forests. Data sets are updated as Renewable Resources Evaluation teams (RRE) gather the data in each region. Frequency of revisions vary from 10 to 25 years.

Useful to policy makers. Available through the U.S. Dept. of Agriculture, Forest Service, Data Base Maintenance Group of RET Program, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

44. Wildlife and Fish 1979 RPA Assessment Data Base

Compilation of wildlife and fish species and habitat data covering the United States and its territories. Developed from data sets of state game and fish agencies. Coverage includes genus, species, common name, list of which of the 64 ecosystems the species may be found, sensitivity class (rare, threatened, etc.), preferred range condition or forest stand age class, whether the species is of commercial or recreational importance, and for some species the consumptive and projected use, and management potential. Includes 1080 birds, 486 mammals, 375 reptiles, 232 amphibians, and 2233 fish.

Useful to scientists, land managers, and possibly policy makers. Available through the U.S. Dept. of Agriculture, Forest Service, Data Base Maintenance Group of RET Program, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO 80526.

45. Soil and Water Resources Conservation Act Assessment, Appraisals and Program 1980 (RCA)

Information documents that describe the status and condition of our soil, water, and related resources--wetlands, riparian vegetation, fish and wildlife habitat, windbreaks, organic residues, and recreation on nonfederal lands. Part I contains an inventory of legislation and regulations dealing with resources and discusses the impact of technology on agricultural production and conservation. It identifies resource areas that concern the public and compares these concerns with available data and conservation problems.

Part II presents projected demands on the Nation's soil, water, and related resources up to the year 2030. It describes assumptions and analytical methods used to forecast these demands and discusses the inherent capabilities and limitations of our resources to meet projected demands. It suggests alternative levels of management that can be used to preserve our resources.

This data base is especially useful to policy makers. Available through U.S. Dept. of Agriculture, Soil Conservation Service, via U.S. Government Printing Office, Wash., DC 20402.

Miscellaneous Data and Information Sources

46. Handbook of Energy Utilization in Agriculture

The book will serve as a source of not only energy expenditures for crop production activity but for the product at the market place as well. The coverage deals with mechanical and heat energy expended for crop production tasks, energy used by the worker as input into food production, energy costs for different foods at different trophic levels and comparative efficiency measures in reducing subsidized energy expenditures in food production. Most vegetable, grain, forage and range products are analyzed in detail for comparative purposes by states and regions of the United States.

Such information is extremely useful to not only the biological scientist but to the land managers and the decision makers as well.

The text is available from CRC (Chemical Rubber Co.) Press, Inc., Boca Raton, Florida. Edited by David Pimentel, Cornell University, Ithaca, New York.

47. Selected References on Rangeland Analysis

Cain, Stanley A., and G. M. de Oliveira Castro. 1959. Manual of Vegetation Analysis. Harper and Brothers, New York. 325 p.

Campbell, J. Baden (ed.). 1969. Experimental Methods for Evaluating Herbage. Publication 1315. Canada Dept. of Agriculture. 223 p.

Joint Commitee of Amer. Soc. Agron., Amer. Dairy Sci. Assoc., Amer. Soc. An. Prod., and Amer. Soc. Range Manage. 1962. Pasture and Range Research Techniques. Comstock Publishing Assoc., New York. 242 p.

Joint Commitee of Amer. Soc. of Range Manage. and the Agricultural Board. 1962. Basic Problems and Techniques in Range Research. National Acad. of Sci.--National Research Council Publication 890. Wash., DC. 341 p.

Lynch, P. B. 1960. Conduct of Field Experiments. New Zealand Dept. of Agric. Bull. 399. 155 p.

Mannetje, L. 't. 1978. Measurement of Grassland Vegetation and Animal Production. Commonwealth Agricultural Bureaux Bull. 52. 260 p.

Mueller-Dombois, Dieter, and Heinz Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley, New York. 547 p.

Pandeya, S. C., G. S. Puri, and J. S. Singh. 1968. Research Methods in Plant Ecology. Asia Pub. House, New York. 272 p.

Phillips, Edwin Allen. 1959. Methods of Vegetation Study. Henry Holt and Co. 107 p.

Southwood, T. R. E. 1966. Ecological Methods. Methuen and Co., London. 391 p.

USDA-Forest Service. 1970. Range and Wildlife Habitat Evaluation--A Research Symposium. Misc. Pub. 1147. 220 p.

USDA-Southern Forest Experiment Station and Southeastern Forest Experiment Station. 1959. Proceedings of Symposium, Techniques and Methods of Measuring Understory Vegetation. 174 p.

48. Selected Range Management Texts

Heady, Harold F. 1975. Rangeland Management. McGraw-Hill Book Co., New York, N.Y.

Sampson, Arthur W. 1952. Range Management. John Wiley & Sons, Inc. New York, N.Y.

Stoddart, Lawrence, A., Arthur D. Smith, and Thadis W. Box. 1975. Range Management. McGraw-Hill Book Co., New York, N.Y.

Vallentine, John F. 1971. Range Development and Improvements. Brigham Young Univ. Press, Provo, Utah.

49. U.S. Dept. of Agriculture, Scientific Education Administration Stations, Centers and Laboratories

The Science and Education Administration-Agriculture Research has a number of centers, stations or laboratories distributed through the western range states that not only carry out day to day range research activity but likewise have much valuable base line data dealing with vegetation changes and production over rather extended periods of time. Most field stations have documented vegetation changes that relate to initial inventory data. They have both plant and animal responses from grazing systems research. Ecological changes and effects of productivity, both primary and secondary, as they are influenced by ecosystem manipulation are available at many of these field stations.

As a result these research centers and stations are an important source of data to aid in subsystem models of the ecosystem or simulation models emulating management strategies. Following is a list of the centers, stations, and laboratories:

Jornada Experimental Range, Las Cruces, New Mexico
Southwest Rangeland Watershed Research Center, Tucson, Arizona
U.S. Water Conservation Laboratory, Phoenix, Arizona
Northern Great Plains Field Station, Mandan, North Dakota
Northern Plains Soil and Water Research Center, Sidney, North Dakota
Livestock and Range Research Station, Miles City, Montana.
Range Insect Laboratory, Bozeman, Montana
High Plains Grassland Research Station, Cheyenne, Wyoming
Central Plains Experiment Station, Ft. Collins, Colorado
Southern Great Plains Field Station, Woodward, Oklahoma
Grasslands-Forage Research Center, Temple, Texas
Poisonous Plant Laboratory, Logan, Utah
U.S. Sheep Experiment Station, Dubois, Idaho
Snake River Conservation Research Center, Kimberly, Idaho
Northwest Watershed Research Center, Boise, Idaho
Squaw Butte Experiment Station, Burns, Oregon

50. U.S. Dept. of Agriculture Forest Service Experimental Ranges

The Forest Service has six field experiment stations that have many range research studies that deal with long term vegetation changes resulting from various grazing systems. As a result these data are considered invaluable for establishing sound ecological principles for managing ranges and likewise for running predictive and simulation models.

These data base areas are important not only to the research oriented scientist but to the range managers and the decision makers as well. The names and locations of the experimental stations are as follows:

San Joaquin Experimental Range (Fresno, California), Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, CA 94701.

Desert Experimental Range (Milford, Utah), Great Basin Experimental Range (Ephraim, Utah), Director, Intermountain Forest and Range Experiment Station, 507 25th Street, Ogden, Utah 84401.

Santa Rita Experimental Range (Tucson, Arizona), Manitou Experimental Forest (Maniton Springs, Colorado), Director, Rocky Mountain Forest and Range Experiment Station, 240 West Prospect Street, Fort Collins, Colorado 80526.

Starkey Experimental Forest and Range (LeGrande, Oregon), Director Pacific Northwest Forest and Range Experiment Station, 809 NE 6th Ave., Portland, Oregon 97232.

51. Ecosystem Data Handbook (Final Review Draft 1979)

The information sources are grouped into three major categories: data systems, referral information, and bibliographic systems. The data systems are those that possess actual data points (e.g., pH measurements at one site), and can be either referenced or unreferenced, automated or manually retrieved pieces of information. Referral systems consist of automated systems, books, agencies, manual files, individuals, etc., that provide information about institutions, automated systems, and individuals. Bibliographic systems produce data points without giving information about a referral system.

The survey made by The Institute of Ecology (TIE) resulted in the identification of some 208 sources of data or information about data, as of January, 1977. Of the 208 sources identified, some 72 either completely, or fully, completed the questionnaire. Examples of these 72 sources relevant to rangelands are listed below.

A listing of this data base information can be obtained from The Institute of Ecology (TIE) at Indianapolis, Indiana, 46208. Examples of summary of the sample of the 208 data bases and information sources identified in the data base information survey. These entries represent only those sources who returned complete or partial survey forms.

Institution, Sponsor or Agency	Name of Data Base	Number of Records	Contact
Canada Center for Remote Sensing	Remote Sensing On-line Retrieval System (RESORS)	10,000 reports	S. Mussakowski, RESORS Manager 717 Belford Road Ottawa, Ontario K1A OY7 613/995-1210
Canada Department of Energy, Mines and Resources	Canadian Index to Geoscience Information	________	Ms. Kay Gunn Canadian Centre for Geoscience Data Canada Dept. of Energy, Mines & Res. 17th Fl, 580 Broth St. Ottawa, K1A QE4
Center for Natural Areas	________	________	W. C. Reed, Pres. J.B. Noble, Vice-President 1525 New Hampshire Ave., NW Washington, D.C. 20036
Council on Environmental Quality	________	ESI Reports	Malcolm Baldwin Exec. Office of the President 722 Jackson Place, NW Washington, D.C. 20006 202/382-5114
Ecological Science Information Center	________	________	Helen Pfuderer, Dir. Information Center Complex Information Division P.O. Box X Oak Ridge, TN 37830 615/483-8611 (36915)
Environmental Information Center	________	________	Jim Kollejger 124 East 39th St. New York, NY 10016 212/685-0955
Lockheed Missiles & Space Co., Inc.	DIALOG Information Retrieval Service	14,000,000 (data)	Roger K. Summit, Program Manager Code 5208/201 3251 Hanover Street Palo Alo, CA 94304 800/227-1960 toll free or 415/493-4411 (45412)

Lockheed Corp.	Lockheed Information Systems Environline		Tom Crawford 3251 Hanover Street Palo Alto, CA 94304 800/227-1960
MITRE Corp.	Monitoring the Environment of the Nation	54 federal projects	MITRE Corp.
National Wildlife Federation	Conservation Directory		Gloria H. Decker, Ed. 1412 16th Street, NW Washington, DC 20036
Nature Conservancy	Nature Conservancy		Robert Jenkins 1800 North Kent Street Arlington, VA 22209 202/254-3151
Onyx Group, Inc.	Environment, U.S.A.	numerous	Onyx Group, Inc. R.R. Bowker Co. 1180 Avenue of the Americas New York, NY 10036
Rocky Mountain Center on the Environment (ROMCOE)			Diane Kareils 4260 East Evans Ave. Denver, Colorado 303/861-1260
Sierra Club		5,000 books 1,200 periodicals 6,500 documents 500 per. subscription	Peter L. T. Messina, Information Services Manager, Sierra Club 530 Bush Street San Francisco, CA 94108 415/981-8634
Smithsonian Institution	Endangered Flora Project	3,000 records	Dr. Ayensu Dept. of Botany Smithsonian Inst. 1730 M Street Washington, DC 202/381-5086
Smithsonian Institution	Abstracts	200,000 + abstracts for past two Federal fiscal years in active search file	Mrs. Janet D. Goldstein Marketing Manager Room 300 1730 M Street, NW Washington, DC 20036 202/381-4211

Smithsonian Institution	SELGEM	2,000,000 species	David Challinor, Asst. Sec. Science Manager Information Systems Division Smithsonian Inst. A & T Room 2363 Washington, DC 202/381-5514
Tennessee Valley Authority (TVA)	TVA		Charles Buffington Division of Forestry, Fisheries and Wildlife Development Norris, TN 37828 615/632-441
UNESCO - Intergovernmental Oceanographic Commission	International Tsunami Information Center (ITIC)	indeterminate	Dr. George Paras - Carayannis, Director P.O. Box 3650 Honolulu, HI 96811 808/546-5688
U.S. Navy	NEPDB (Pearl Harbor Area Naval Environmental District Data Base)		S. M. Brainin, Head 14th Naval District Box 110 FPO San Francisco, CA 96610
University of Alaska	Arctic Environmental Information & Data Center	3,000 records	Linda Dwight Dreyes, Supervisor 707 A Street Anchorage, Alaska 99501 907/279-4523
University of California	Sources of Information in Water Resources	1100 titles	Gerald J. Giefer, Librarian Water Resources Center Archives Univ. of California Berkeley, CA
U.S. Environmental Protection Agency	Directory of State Agencies Engaged in Environmental Monitoring		Head EPA, Office of Research & Development Washington, DC 20460
U.S. Environmental Protection Agency	Environmental Information Systems Director		Head Data Systems Division Room 3101 401 M Street EPA Washington, DC

U.S. Environmental Protection Agency	STORET	34,000,000 observations	Phil Linderstruth Water Quality Analysis Branch EPA 401 M Street Washington, DC 202/426-7792
U.S. Department of the Interior	Water Resources Scientific Information Center	99,000	Mr. Raymond A. Jensen Manager Office of Water Research and Technology 18th and C Streets, NW Room 1308 Washington, DC 20240 202/343/8435
U.S. Department of the Interior, USGS	WATSTORE	100,000 sites	Russel Langford, Chief Geological Survey Reston, VA 22092 703/860-6931
U.S. Environmental Protection Agency	Director of EPA, State, and Local Environmental Quality Monitoring	____________	John W. Scotton, Office of Research and Development USEPA Washington, DC 20460
U.S. Department of Energy	National Inventory of Selected Biological Monitoring Program	1,027 with full documentation 3,192 partial documentation	H.T. Kemp, Project Dir. Bldg. 2001, Environmental Sci. Div. ORNL, P.O. Box X Oak Ridge, TN 37830 615/483-8611 ext. 3-0391
U.S. Department of Energy	Numerical and Textual Information Systems (NUTIS)	150 IBP data sets	Dr. Rodney Strand Environmental Sci. Div. P.O. Box X Oak Ridge, TN 37830 615/483-8611
U.S. Department of the Interior, USGS	EROS Data Center	6,000,000 (data)	User Services Sioux Falls South Dakota 57198 605/594-6511
U.S. Department of the Interior, USGS	National Water Data Exchange (NAWDEX)	80,000 sites	R. H. Lanford, Chief U.S. Geological Survey U.S. Dept. of Interior Reston, Virginia 22092

U.S. Department of the Interior	Sensitive Wildlife Information System		Dr. V. E. LaGarde Corps of Engineers Vicksburg, MS 601/636-3111
U.S. Department of Energy	Bio Monitoring Inventory Project	3,086	Jack Kemp Oak Ridge National Laboratory Building 3504 Oak Ridge, Tennessee 615/483-8611 (30394)
U.S. Department of Energy	ESIC (Ecological Sciences Information Center)	20,000 documents	Helen Pfuderer, Dir. Building 2029, Box X Oak Ridge National Lab Oak Ridge, TN 37830 615/483-8611 (3-6173)
U.S. Department of Energy	GIS (Geoecology Information Systems)	1,330,000 (data)	Dr. F. Glenn Goff Research Staff Member Mr. Richard J. Olson Research Staff Assoc. Environmental Sci. Div. ORNL Oak Ridge, TN 37830 615/483-8611, ext. 3-6012
U.S. Department of Agriculture, Forest Service	ECOSYM		Lawrence R. Davis Department of Forestry and Outdoor Recreation Utah State University Logan, Utah
U.S. Department of Agriculture, Forest Service	Land Inventory and Monitoring Program (LIM)		Head USDA, Forest Service Land Inventory and Monitoring Washington, DC
U.S. Department of Commerce, NOAA	National Climatic Center (NCC) (Data Bank)	Indeterminate, but very large	Environmental Data Service Information Services Division Federal Building Asheville, NC 28801
U.S. Army Corps of Engineers	Environmental Atlas		Head Librarian Army Corps of Engineer Library Forestall Bldg. Washington, DC
U.S. Army Corps of Engineers	State Environmental Inventory Activities		Head Librarian U.S. Army Corps of Engineers Forestall Bldg. Washington, DC

Background Paper No. 25

IMPACTS OF TECHNOLOGY ON CROPLAND AND RANGELAND PRODUCTIVITY: MANAGERIAL CAPACITY OF FARMERS

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SUMMARY

1. There are a number of ways in which the managerial capacity of farmers can influence the maintenance and enhancement of the long-term productivity of U.S. cropland and rangeland resources. This influence occurs through the farmer's ability to use existing and future technologies in an efficient and effective manner.
2. A comprehensive model of farm management (managerial capacity), in both a theoretical and measurement sense, does not exist. Most research in the area of farm management has had a heavy economic emphasis. This limits the usefulness of these models to address productivity issues involving social, political, or ecological questions.
3. The relation between managerial capacity and maintaining the long-term productivity of the land remains uninvestigated. A few studies are beginning to point out the importance of managerial capacity in explaining farmers' adoption of soil conservation practices. However, these studies have failed to measure managerial capacity in a comprehensive or consistent manner.
4. There are strong interaction effects among the socioeconomic correlates of managerial capacity. Farmers with poorer managerial capabilities are more likely to have lower educations, smaller farm operations, a greater dependence on non-farm income, and situated on more erosion prone land than farmers with higher managerial capacities.
5. Existing conservation policy, which would enhance the long-term productivity of the land, has been largely ineffective because of a lack of flexibility. This lack of flexibility is especially apparent in a number of assumptions underlying current implementation strategies.
6. Policy designed to enhance or maintain the long-term productivity of U.S. cropland and rangeland should recognize the distinction between farmers who cannot and those who will not adopt the recommended conservation technologies.

Impacts of Technology on Cropland and Rangeland Productivity: Managerial Capacity of Farmers

Introduction

Soil erosion is an ancient and persistent enemy of man. The loss of productivity in eroded soils has been associated with the fall of city states and civilizations (17, 9). The Four Horsemen of the Apocalypse have always rampaged easier across eroded cropland and fields. Excessive erosion recognizes neither political nor economic boundaries and remains a serious problem in both developing and developed nations. It has been suggested that the greatest single fault of mankind through the annals of recorded history has been his failure to preserve and protect the natural resources which provide the basic necessities of life; food clothing, and shelter (33). The United States is not an exception to this indictment as early, westward, migration patterns have been attributed to losses in the productivity of the land (30,35). Today, erosion of topsoil and the concomitant loss of productivity is being recognized as a major threat to the viability of the nation's future. The increasing dependence on agricultural exports to compensate for petroleum imports in conjunction with the expanding use of food as a mechanism for international diplomacy makes maintaining the nation's agricultural productivity a critical issue.

Productivity and Soil Erosion

In a general sense there are three analytical questions associated with the relation between soil erosion and the land's productivity. First is a question relating to how erosion of topsoil influences productivity. Soil erosion can disrupt the structure and fertility of the soil ecosystem which largely determines its productivity potential. The nature of these ecological processes will not be discussed in this report. Once this process is understood, the second question is concerned with the extent to which it is occurring. To what extent is soil erosion jeopardizing the productivity of the nation's agricultural lands? Again, addressing this second question is beyond the scope of this report. A third question, the one addressed in this report, attempts to determine how technology can either exacerbate or alleviate this relationship between agricultural productivity and soil erosion by examining the farmer's ability to use technologies.

Productivity refers to the ability of the land to sustain current or increasing levels of production of crops, forage, and ecological services. This ability is influenced by three interdependent sets of technological factors:

(1) Technology is used to manipulate the characteristics of the soil and water resources upon which all crops, forage, or ecological services depend. Irrigation, fertilizers, conservation structures, herbicides, and pesticides are some of the more obvious examples of how technology can affect the strucuture and the fertility of the soil.

(2) The agronomic processes by which these crops, forage, or ecological services are cultivated is closely associated with existing technologies. Specialization, innovative rotation systems, and the many different forces of agricultural mechanization have had profound impacts on productivity by changing the manner of production.

(3) The biological nature of the crops, forage or ecological services can be manipulated by technology to enhance productivity. Improved seeds and plants have brought higher yields while also increasing weather resistance, disease resistance, and insect resistance.

Emerging technologies and productivity growth are identified in Figure 1.

There is, however, an additional factor missing from this standard characterization of how technology affects cropland and rangeland productivity. An equally important consideration is man's ability to use these technologies in an efficient and effective manner. Efficiency is in the sense of being able to use available technologies to transform the inputs to the farm* firm into outputs, i.e., forms of productivity. Effectiveness refers to the ability of management to obtain, maintain, and exchange resources (land, labor, capital, and knowledge) within the larger political economy. When analyzing the ability to use available technologies in an efficient and effective manner, we are referring to a farmer's managerial capacity.

Importance of Managerial Capacity

It is often assumed in agricultural programs or policy initiatives that all farmers have similar capacities for implementing technologies in an efficient and effective manner. Capacities include such necessary resources as capital, knowledge, and management skills. Actually, many farmers are lacking some or all of these resources. For example, a farmer might initially adopt a conservation practice made profitable through policy incentives, but because of lack of critical management skills and the failure to integrate the practice into the overall farming operation, the final result will be a reduction in yields and annual profits. Further, the individual may become convinced that the fault is in the conservation practice and therefore would be more likely to reject future efforts in this direction. Economic incentives or technological sophistication alone cannot make a practice either profitable or appealing to all farmers. Understanding farmers' managerial capacity as it relates to the adoption of conservation practices will be an important factor in maintaining the productivity of our agricultural lands (25).).

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* the terms farm and ranch are treated as synonymous

Managerial Capacity: A Theoretical Overview

Farm management, agricultural decision making, the management factor, or managerial capacity has been examined extensively in the research literature (13,18,19). Although there is a lack of both theoretical consensus and empirical verification in this area (18), certain general statements can be made. Managerial ability is associated with eight interdependent processes (20,24): (1) formulation of the goals or objectives of the firm; (2) recognition and definition of a problem or opportunity; (3) obtaining information -- observation of relevant facts; (4) specification and analysis of alternatives; (5) decision making -- choosing an alternative; (6) taking action; (7) bearing responsibility for the decision or action taken; and (8) evaluating the outcome. These processes are directed toward three major problem areas (21); production and organization, administration, and marketing (see Figure 2). In working toward resolving these management functions, the operator can depend on both direct and indirect sources of managerial resources (10). Direct resources are those supplied by the farm operator, members of his family and his employees. Indirect managerial resources are those which originate outside the farm family operating unit. This can include professional management services, integration services, and institutional resources. This latter category refers to managerial resources received from government programs, financial institutions, educational institutions, and farm cooperatives. Finally, the eight managerial processes which are directed toward the three problem areas, using both direct and indirect management resources, are affected by the operator's values and goals (11). Numerous studies have demonstrated that profit maximization is not always the dominant goal in farm decision making (2,15). Maintaining traditional agrarian values, leisure, family, freedom, reduced risk, stewardship, and prestige all offer alternative orientations to profit maximization.

A review of the literature in the area of farm management results in two general conclusions. First, a comprehensive model of farm management does not exist. This condition reflects the complex array of economic, social, and behavioral factors which influence managerial abilities. The economic processes associated with managerial capacity have received the greatest amount of attention, and this fact is reflected in the theoretical and empirical sophistication of the economic sub-models. However, when examining managerial capacity there has been excessive reliance on empirically based economic models to the exclusion of the more qualitative political, social, agronomic, and psychological factors. All should be included in a comprehensive model of farm management.

A second conclusion is that the relation between managerial capacity and maintaining the long term productivity of the land has not been investigated. It appears that there is a common assumption that a good farm manager, defined in terms of an ability to generate a profit, is also a good steward. This assumption is questionable in that one can be a good steward and still generate a profit, but generating a profit does not always lend itself to good stewardship. We need a better understanding of the factors involved with both managerial capacity and stewardship of the soil.

Causal Mechanisms: Managerial Capacity, Soil Erosion, and Productivity

There are a number of social, socioeconomic, and demographic factors which are related to farmers' stewardship of the productive capacity of their land resources. Stewardship, as a belief system among farmers, refers to the interdependency between man and the environment (26). These beliefs area as follows:

(1) a belief that a steward has a moral, as opposed to ecological, obligation to maintain natural resources.

(2) a belief that ownership of the land is a relative matter.

(3) a belief that stewardship involves the enactment of responsibility to the larger social community and future generations regarding the use of natural resources.

(4) a belief that a steward must utilize his land so that it is enhanced and passed on to his children in a better ecological condition than originally obtained.

A belief in stewardship has been found to be directly related to the perception of and concern with soil erosion as a serious environmental problem (26). At issue are the socioeconomic charactertics of the farm operator which are associated with the practice of stewardship. Both characteristics of the farm operator and the farm firm can influence the use of conservation behaviors which impact on the productivity of the land.

There are two competing arguments concerning the relation between sets of various socioeconomic factors and conservation behavior. A general overview of these arguments will be presented prior to investigating some specific causal factors.

One of the arguments emerges from the more general critique of the growing scale and concentration of North American agricultural production (7,27). First, it is suggested that prevailing agricultural technologies are primarily intended for and enhance the position of large-scale farmers (7). Large-scale machinery and energy -- and capital -- intensive technologies are primarily suited for the large-scale farmer because of constraints on capital and credit availability on the part of small farmers (7). Further, relative to the nature of this report, these large-scale farmers either have higher levels of direct managerial resources, or greater access to indirect sources of managerial resources, and therefore they are more able to use these intense agricultural technologies. It is also argued that these technologies place larger farmers at a competitive advantage vis-á-vis smaller farmers while also contributing to higher levels of environmental degradation. The use of these technologies, it is posited, restricts the ability to implement conservation practices. Another theme in this argument is that the government has disproportionately subsidized the large-scale farmer through commodity programs, irrigation subsidies and research policy (4,31).

Finally, it is argued that this inverse relationship should exist because large-scale farmers are more vulnerable to shifts in market forces and therefore have little choice but to postpone attempts at conservation in order to maximize short-term profitability.

An alternative and competing argument is that there is a direct relationship beween the class status of the farmer and behavior which supports the long-term productivity of the land. The theoretical basis for this hypothesis comes from both the environmental and adoption-diffusion literatures where social class, often operationalized as some combination of education, occupation, or income, is positively related to environmental concern and innovative behavior (6,28). Individuals with these characteristics are more aware of the processes contributing to environmental degradation as well as the consequences for the agricultural ecosystem. Supposedly, they are also more able to perceive any relative advantage or compatibility of conservation practices for their own operation. A number of studies have found a positive relationship between indicators of social status on farm size and conservation behavior (16,12,5,8). Further evidence relative to these two competing arguments will be presented later following examination of some specific causal factors.

Age

The age distribution of the U.S. farm population and nonfarm populations are presented in Table 1. The farm population had an older age structure than the nonfarm population and thus a higher median age. In 1979, the median age of the farm population was about 34 years, as compared with about 30 years for nonfarm residents. Although there was no significant difference in the proportions of children and teenages, and of the elderly, the farm population had a lower proportion of young adults (20 to 34 years) and a higher proportion of middle-aged persons (35 to 64 years) than the nonfarm population (1).

There are several different influences that age can have on farmers' behavior or decision-making relative to changes in the long-term productive capacity of their land resources. Older farmers often have a limited formal education which restricts their ability to adopt newer technologies. Therefore conservation practices dependent on the adoption and maintenance of newer technologies will be less successful among older farmers because of their limited managerial capabilities. It is also possible that older farmers with no heirs operate under shorter planning horizons than younger ones (23). This would be especially true for those conservation practices with long-term payoffs. On the other hand, many conservation practices which maintain the productivity of the land have been in existence for some time. Older farmers who have more experience with these practices are often able to successfully use them while integrating the practice into their overall farming operation. Thus, the relation between age and managerial capacity as it relates to maintaining productivity is often mediated by the 'newness' of the technologies employed.

Education

Age and education among farmers is highly correlated. In 1970, 72 percent of farmers who were 55-64 years old had not finished high school. However, only 12 percent of young farm operators 20-24 years of age had failed to finish high school, and more than 25 percent had some college training (3). Although it is not an unvarying law, the amount of formal education is directly associated with managerial capacity. Those farmers with a better education often translate this into greater managerial skills which is reflected in larger and more prosperous farm operations. More importantly, there also is a direct relationship between managerial capacity and the use of conservation practices which enhance the productivity of the soil (22). Education often serves as an indirect indicator of managerial capacity.

Size of Farm

Size of a farm will refer to the scale of operations within any commodity group. This is frequently measured by number of acres, net farm income, total wealth, or some combination of these factors. As mentioned earlier, there are two alternative positions on the relation between farm size and conservation behavior. Some have argued that large farms degrade the land to a greater degree than small farms, whereas others have found a direct relation between size of farm and conservation behavior. For a number of reasons specified later, the author maintains there is a curvilinear relation between size of farm and conservation behavior. Operators of very small farms are often unable to adopt the necessary conservation practices, whereas operators of very large farms are often unwilling to adopt these practices. Most conservation behavior occurs among the middle range of farms.

The scale of operations is directly related to managerial capacity. Either direct or indirect managerial resources are needed to attain and maintain a large farming operation. Some agronomic practices are capable of conserving the productivity of the soil while achieving savings in time, energy, or labor, e.g., conservation tillage. The ability to recognize these characteristics and to adopt the appropriate technologies is a correlate of managerial capability (22).

A number of analysts have noted that farms are becoming fewer in number and larger in size (29). Good farm managers who adopt certain conservation practices are likely to contribute to this trend in the future. Savings in time, labor, and energy resulting from the use of these practices not only reduce production costs, but it also creates a "push factor" toward expanding the farm operation. Proficient managers with excess time and capital will look for additional farmland to invest these resources.

Tenure

Several studies have demonstrated that the amount of erosion control adopted is directly linked to whether the farmer owns or rents the land (5,12). It is argued that owners are more likely than renters to employ conservation practices because owners aremore likely to reap any long-term ecological benefits from using these practices (14). Owners, as opposed to renters, also are impacted more directly by the institutional processes such as economic incentives and legal regulations.

Recent research indicates that this tenure/conservation behavior relationship is mediated by farm income (23). Landowners in the very low and the very high farm income categories have significantly higher erosion rates than landowners in the middle categories. Comparable data for renters is not available.

Escalating land prices might also cause an owner-operator who has recently purchased land to "mine the soil" to compensate for the high purchase price. In attempting to explain conservation behavior, when one became an owner could be just as important as whether one is an owner or renter. This would be especially applicable to young, beginning farmers who, although they have the necessary managerial skills, could be put in a position in which it is economically impossible to use the necessary conservation practices.

Interaction Processes

There are few simple causal relationships when examining managerial capacity, agronomic behaviors which influence the long-term productive capacity of the land, and the previously discussed socioeconomic factors. A possible explanation for these mixed findings is that the better farmland, that land having less need for erosion control practices, is more likely to be operated by the more prosperous farmer. This farmer on the better-quality land also is more likely to have a better education, greater managerial capacities, greater flexibility with economic resources, and a higher level of integration into local and state conservation networks. It is the farmer with the larger operation on the better land that is more likely to be receiving cost-sharing payments and technical assistance. On the other hand, the tenant farmer, or the smaller operation located on the poorer land does not have the matching funds necessary to receive cost-sharing payments in the first place. Futher, even if they were to receive these funds, they often lack the managerial capabilities to take advantage of today's technical assistance programs.

There has been relatively little research which has examined this set of hypotheses. These investigations have confimed several of the individual hypotheses, but the overall argument remains untested. For example, a recent, unpublished report based on national data concluded that:

> "...only 40 percent of cultivated cropland owned by the most affluent landowners is classified as having an erosion hazard, while 59 percent of cultivated cropland owned by the lowest

> income group is labeled erosion prone. This trend can be found in most of the regions of the United States. In terms of management, 60 percent of cultivated cropland owned by landowners with net farm income greater than $50,000 had minimum tillage or residue practices in effect, while 47 percent of such land owned by those with net incomes of less than $3,000 had these practices at the national level" (23).

Additional implications of these interaction processes are examined in the next section.

Conservation Policy as a Form of Planned Change

The effort to have farmers adopt conservation practices is bascially under the rubric of planned change. The traditional approach has been to facilitate the implementation and continued use of conservation practices through technical assistance and cost-sharing. Additionally, educational programs have been used to make farmers aware of soil erosion problems and to inform them of practices and assistance available to help solve these problems. However, there is widespread agreement that previous efforts have largely failed in conserving soil and water resources ( ).

One reason for the failure of this traditional policy approach is the inflexibility in implementation to allow application to different target groups based on some of the factors discussed in this report. Zaltman and Duncan (36) specify four components that must be present within the target audience to some degree for any program of planned change to be effective. First, there must be an awareness of the problem as well as an awareness that a solution to the problem exists. Second, there must be a felt need by the target audience for a solution to the problem, that is, the group must desire better conditions. Third, once there is an awareness of the problem and felt need for improvement, then the group must have a commitment, usually expressed in terms of resources of some kind, for seeking a solution to the problem. Finally, building upon the first three conditions, no action will be taken, or the action taken will be ineffective resulting in eventual abortion of the project, unless the individuals or groups have the capacity to affect the solution. This capacity refers to the utilization of necessary resources such as money, knowledge, skills or influence. Recognizing managerial capacity underlies the successful implementation of any conservation policy.

Of course, the traditional approach theoretically provides the individual farmer with the capacity to implement agricultural conservation practices through education, technical assistance, and a certain level of cost sharing. And, this would certainly be realistic if all farmers in all places had, first, the same level of erosion severity on their farms and were able to recognize erosion as threatening the long-term productivity of their land; second, that all farmers in all places wanted to do something about this erosion problem in order to preserve the land's productive capacity; third, that they all had excess resources and time to commit toward the solution of the problem; and, finally, that they all had the same capacity, such as flexibility in investment capital and management skills, to implement these conservation practices. Unfortunately, as this report has attempted to document, this is not the case. There is extensive variation among farmers in terms of the actual and felt need for conservation practices, as well as the willingness and actual capacity to adopt them. This variation is often ignored in the formulation and implementation of conservation policy.

Assumptions of Conservation Policy

Because current policy ignores the variation among farmers, it lacks the needed flexibility for promoting the implementation of conservation practices. At fault are several assumptions of the infrastructure of current policies. One common assumption is that this policy is directed toward rational men. This assumption posits that all men are guided by reason and through presentation of adequate information they will arrive at the correct conclusion. We see this rationalistic bias present in a number of places within current policy. There are many different criteria by which rationality can be assessed such as being ecologically rational, socially rational, or economically rational. However, economic criteria are the mainstay in formulating conservation policy. According to this rational man assumption, if we can offer a large enough incentive or if we can somehow just make conservation practices a "break-even" proposition, or even slightly profitable, there would be no difficulty in getting farmers to adopt the needed conservation measures. This assumption ignores the influence of agrarian ideologies, the often expressed importance of maintaining traditional farming methods, or even the viability of alternative farming systems such as those incorporating organic methods. Further, this assumption views all farmers as having similar capacities, whether these capacities are additional capital, knowledge or management skills, for implementing these 'profitable' conservation practices.

A second assumption often guiding the formulation of conservation policy is that access to knowledge and information is distributed homogeneously across any group of farmers. This assumption is simply not valid.

Research on the adoption and diffusion of agricultural innovations has shown that access to information is neither available nor simultaneously diffused through all parts of a system. Information diffuses through a system via specific communication networks to which individuals in the system have differential access. Furthermore, and this relates back to the importanct of a formal education, individuals have different base levels of knowledge as well as the capacity to assimilate new knowledge. Therefore, by just increasing the flow of knowledge into a group of farmers, which is the typical procedure of any educational program, *there is a strong possibility of magnifying the existing knowledge gap rather than decreasing it*. We cannot assume that these general educational programs will inform farmers equally of the existence of a problem, create a felt need to do something about it, or instill the capacity to accept and implement whatever technical or economic assistance is provided.

A third assumption is that individuals act individualistically, that is, they are not influenced by those in the social system around them. However, even the most independent of farmers is subject to the approval or disapproval of his peers. Changes in conservation behaviors that are not supported or reinforced by the farmer's neighbors or opinion leaders of the community are unlikely to occur, or even if they do occur, they will not be maintained for any length of time. Yet, most efforts at promoting soil conservation are directed toward individual farmers rather than working through neighborhood, community, or kinship approaches. Again, these change efforts are largely directed toward the more receptive, progressive, and innovative farmers who are also generally the larger, more prosperous farmers. Further, as was mentioned in an earlier section of this report, it is these same farmers whose lands have less need for conservation measures in the first place as they often farm the better land within any farming area. Thus the individualistic approach to promoting change in soil and water use behavior engendered by current policy is most effective with individuals who have the least need for educational, technical and monetary resources.

In short, these often implicit assumptions underlying the formulation of conservation policy have tended to minimize critical differences within the farm population; differences which constrain the effectiveness of any policy. To be effective, conservation policy must be flexible enough to accomodate these differences.

Factors in Policy Design

Ideally, policy should be designed so that it facilitates the use of conservation practices which maximizes the welfare of both the public and the farmer. However, there are a number of problems which may prevent this welfare maximization. The problem addressed in this section is that not all farmers are willing or able to adopt the recommended practices which preserve the long-term productivity of the land. There is a significant difference between those farmers who cannot and those who will not adopt the recommended practices. The reasons for this difference as well as the appropriate implementation strategy for each situation are outlined in Figure 3. These categories have been developed for heuristic reasons, and their position in the diagram is not meant to imply that they are mutually exclusive. Farmers can be both unwilling and unable for several of the reasons listed. Nevertheless, this diagram begins to detail some of the complexity involved with recommending a practice that is economically optimal, agronomically effective, and socially equitable.

FIGURE 3

SITUATION RELATIVE TO ADOPTION	REASON FOR NOT ADOPTING	IMPLEMENTATION STRATEGY
Unwilling to Adopt Practices	Competing Goals	"Red Ticket"
	Lack of information	Education
Unable to Adopt Practices	Lacking Managerial Capacity	Education
	Lacking Sufficient Capital/Land	"Green Ticket"

Farmers Who Are Unwilling to Adopt Practices Which Maintain Productivity

In general, there are two reasons why farmers are unwilling to adopt a recommended practice. First, competing goals such as a profit orientaion or maintaining traditional farming methods are valued higher than the goals associated with resource conservation. Second, farmers may be unwilling to adopt because they lack adequate information on either the process or the implications of using the recommended practice. The most common explanation for farmers' unwillingness to use the appropriate management procedures is the perception that these practices will hinder profitability of the farming operation. Of course, profit making must be a legitimate concern or the farm firm would soon cease to exist. However, the extent of profit is another issue. If the level of profit is such that the incorporation of conservation practices into the farming operation would not jeopardize the economic viability of the firm, then a "red ticket" implementation strategy is appropriate. A red ticket strategy consists of fines, cross-compliance with other USDA programs, taxes, and penalties for excessive soil loss and water degradation. But if this strategy creates financial hardships -- threatens the economic viability of the firm -- then a "green ticket" implementation strategy would be more appropriate as indicated in the bottom cell of Figure 3. A green ticket strategy implies cost-sharing, financial incentives, or low interest loans.

The second reason why farmers may be unwilling to adopt the recommended practices is that they lack adequate information. They may need more information on how the practices is to be implemented, how it fits into the larger farming operation, or what the consequences will be for using the practice. Again, managerial capacity becomes an important consideration. Many of these questions can be answered only after using the practice, perhaps on a limited or trial basis. Users and non-users have different perceptions of the characteristics associated with any conservation practice. These differences are illustrated in Table 2 containing comparisons of relevant characteristics for mimimum tillage, contour planting, and terraces.[1] Users and non-users have significantly different perceptions of the same practice, as well as significant variations between practices on the same characteristic. For example, 80.5% of the users felt that minimum tillage was fairly compatible with their operation, but only 42.9% of the non-users thought this practice would be compatible. However, in considering terraces, only 48.1% of the users perceived this practice as being fairly compatible, and 12.3% of the non-users thought it would be compatible. Other comparisons can also be made on the basis of the data presented in Table 2. This evidence suggests that farmers who are presently unwilling to adopt a recommended practice will gain additional information and change their perceptions if they adopt the practice on a trial basis. An implication for implementation strategies is the incorporation of trial adoptions to facilitate acceptance of recommended management practices.

Farmers Who Are Unable to Adopt Practices Which Maintain Productivity

An entirely different situation exists when individuals are unable to adopt the recommended practices. Again, two reasons emerge when examining this group of farmers. The first reason for inability to adopt a recommended practice is because of lack of necessary management skills, a common theme in this report. For example, different forms of reduced tillage have frequently been identified as highly effective conservation practice. Yet, even though fewer operations are involved, the sequence and success of these operations are more critical. The necessity of dry soil conditions prior to spring tillage, greater field to field variation

[1] See Footnotes

in weed control and fertility maintenance, and the necessity for operations to be successful on the first run all make management skills a critical factor. Even with financial incentives, reductions in annual yields and profits are very likely if a farmer attempts to use a management practice for which he lacks the necessary skills.

Although the concept of management skills is in itself very complex, an additional important facet of managerial success is related to different sources of information. Farmers in the cited survey were asked about their most important source of soil conservation information. These responses were then classified by low, medium, or high use of conservation practices by the farmers. This classification is based on the assumption that high users of conservation practices are more likely to have management skills that low users might be lacking. As seen in Table 3, those farmers who were using 5 to 8 practices in their operation were much more likely (80%) to use government agencies as their major source of conservation information. On the other hand, there was a more random distribution of sources as well as a dependence on friends and relatives among the medium and low users of conservation practices. This provides a rough indication that managerial skills, at least those reflected in the choice of information sources, are closely associated with the adoption and use of the recommended practices. Educational strategies are most appropriate to facilitate adoption with this group of farmers as neither penalties nor incentives would really address the underlying problem.

A second reason why farmers are unable to adopt the recommended practices is that they lack the necessary capital and/or land. Small-scale, part-time, or marginal farmers often have cash flow problems which make investment in additional farm implements or time consuming practices difficult. They are limited in their adoption of new agronomic practices by their existing machinery inventory. Further, off-farm employment will limit the amount of time they have for either setting up or facilitating a new management procedure.

Short-term lease arrangements on rented land discourages the farmer from adopting practices which have long-term productivity benefits. Implementation strategies in this case should be oriented toward providing incentives to landlords who will give tenants long-term leases with the understanding that specified practices will be used.

Farmers, then, are both unwilling and unable to adopt the practices which protect the long-term productivity of the land. The role of conservation policy should be twofold in order to acknowledge these social processes. First, design goals related to the protection of the land's productive capabilities which minimizes the number of farmers who are put into the situation of being either unwilling or unable to adopt the recommended practices. To do this, we need a better understanding of the relationship between the impact of these practices and their impact on the long-term productivity of the land. We need to know whether different practices can be substituted to achieve the same ecological ends, but which may have different socioeconomic consequences for the farmers attempting to use these practices. To compliment this end, we need a better understanding of why and how farmers come to be unwilling and unable to work with these practices. Many of the socioeconomic processes discussed in this report needs to be investigated relative to their impact on the farmer's ability to adopt the necessary technologies. Secondly, conservation policy should include implementation strategies which explicitly recognize the reasons farmers are not adopting the recommended practices, and then work toward resolving those problems. Flexible strategies which recognize the variation between farm operations along critical social and economic dimensions would be a step in the right direction.

FOOTNOTES

1. The data used in this report is taken from the project, "Effect of Agricultural Land Use Practices on Stream Water Quality: Sociological Factors in the Adoption of Best Management Practices." Sociology's effort is sponsered by the Environmental Protection Agency, Grant Number R806814-01-2.

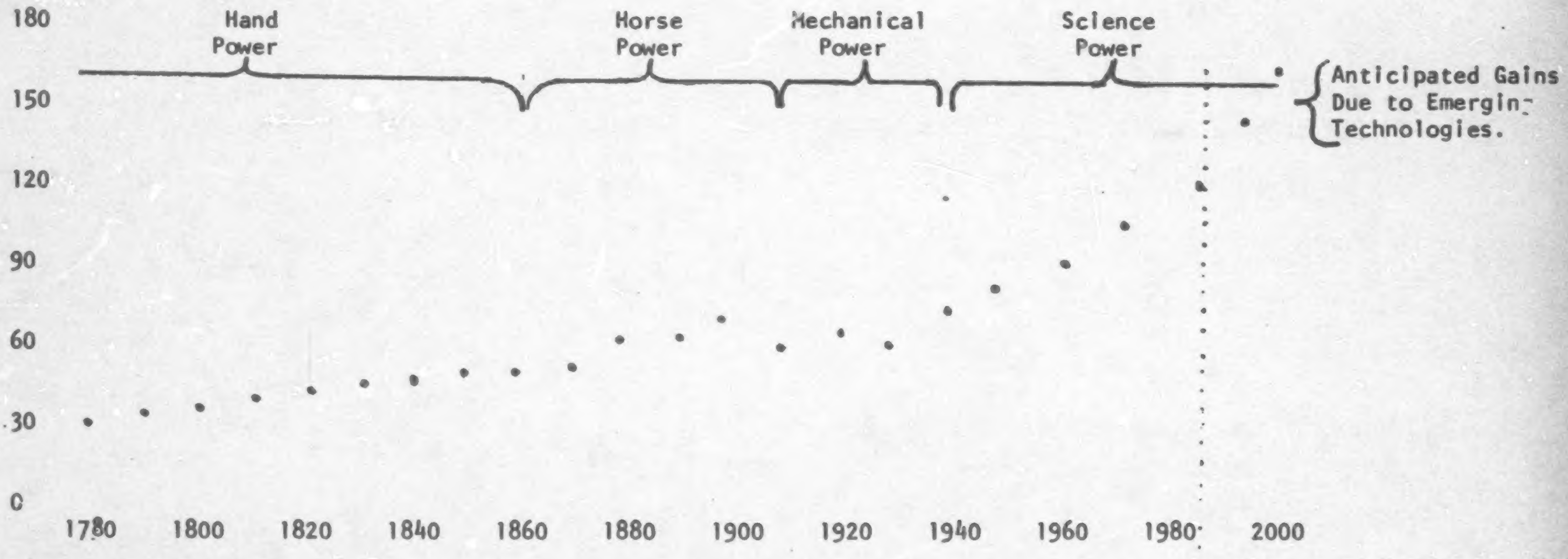
Sociology's role was to determine the socioeconomic and institutional processes which influence the awareness, adoption, and maintenance of selected conservation practices. To achieve this end a research design involving a pre-test and post-test on both control and experimental groups is being carried out. The experimental group refers to all farmers operating within the Four Mile Creek watershed, Tama county, Iowa. Additional cost sharing funds provided by the ASCS, supplementary technical assistance by the SCS, increased educational efforts by the Cooperative Extension Service, and the research efforts by the Iowa State University departments of Agronomy, Agricultural Engineering, Agricultural Economics, and Sociology provide the treatment effects for this watershed.

Two additional watersheds in Iowa were selected for control groups. A number of watersheds were matched with the Four Mile Creek watershed on the basis of size, soil association, slope, and dominant cropping practices. The Mud Creek watershed in southeastern Benton county and the Rock Creek watershed in northcentral Cedar county were finally selected.

Preliminary socioeconomic, demographic, and farm firm data were gathered from 73 operators in Four Mile Creek watershed, 55 operators in Mud Creek watershed, and 65 operators in Rock Creek watershed. Additional data gathering will occur in early spring of 1981.

Figure 1: PRODUCTIVITY GROWTH, 1780 - 2000 (34)

(U.S. Agricultural Productivity Growth, % of 1967)



EMERGING TECHNOLOGIES (USDA, ESS, Agricultural Information Bulletin No. 439)

Some of the most likely areas of future technology are:

- -Enhancement of photosynthetic efficiency, which increases the rate at which plants grow, to improve their yield.
- -Better water and fertilizer management to increase plant production.
- -Better pest control strategies that use less energy, cost less, and rely on more natural means to discourage pests rather than on chemically formulated pesticides.
- -Growing more plants in greenhouses--probably limited to high value and speciality crops.
- -Inducing multiple births in beef cattle.
- -Multiple cropping, that is, planting and harvesting more than one crop per growing season on the same land.
- -New machinery and equipment.
- -Automated processes that reduce labor requirements.
- -Bioregulators
- -New crops, new and improved hybrid strains.
- -Bioprocessing, to allow more of the harvested plant to be used.
- -Antitranspirants, which inhibit plants' evaporation of water and allow plants to withstand drought and salinity.

Figure 2: Problem Areas of the Management Function

- PROBLEMS OF THE FARM MANAGER
  - PRODUCTION AND ORGANIZATION PROBLEMS
    - How to get land
      - Purchase
      - Lease
      - Rent
    - How to maintain land
      - Conservation practices
      - Conservation structures
    - What to produce
      - Enterprise mix
      - Production processes
      - Government programs
    - Scale of production
      - Large scale
      - Medium scale
      - Small scale
    - Equipment
      - Size
      - Specialty
      - Ownership
      - Custom hiring
  - ADMINISTRATIVE PROBLEMS
    - Credit and capital acquisition
    - Supervision of work
    - Operational timing
    - Production systems
    - Production and performance records
    - Accounting and bookkeeping
  - MARKETING PROBLEMS
    - Buying
      - What to buy
      - When to buy
      - From whom to buy
      - How to buy
      - With what to buy
    - Selling
      - When to sell
      - To whom to sell
      - How to sell

Table 1: Farm and Nonfarm Population by Age, 1979

Numbers in thousands (percent of total)

Age	Farm	Nonfarm
All ages	6,241 (100)	209,067 (100)
Under 20 years	2,086 (33.4)	68,628 (32.8)
20 to 34 years	1,086 (17.4)	52,370 (25.0)
35 to 64 years	2,342 (37.5)	65,570 (31.4)
65 years and over	727 (11.6)	22,500 (10.8)

TABLE 2 : Perceived Characteristics of Soil Conservation Practices

CHARACTERISTIC	MINIMUM TILLAGE		CONTOUR PLANTING		TERRACES	
	(N=154)	(N=35)	(N=116)	(N=61)	(N=27)	(N=155)
	USERS	NON-USERS	USERS	NON-USERS	USERS	NON-USERS
Cost For Using[1]						
no cost	49.3%	38.2%	52.6%	21.0%	22.2%	2.6%
moderate cost	47.4%	35.3%	43.1%	54.8%	51.9%	17.8%
very high cost	3.3%	26.5%	4.3%	24.2%	25.9%	79.6%
	100 %	100 %	100 %	100 %	100 %	100 %
Profitability						
costs exceed returns	7.8%	21.9%	5.2%	45.9%	20.0%	58.2%
costs equal returns	32.5%	46.9%	44.4%	37.7%	32.0%	27.4%
returns exceed costs	59.7%	31.2%	50.4%	16.6%	48.0%	14.4%
	100 %	100 %	100 %	100 %	100 %	100 %
Time/Labor Requirements						
more time/labor	7.8%	20.0%	66.4%	89.1%	53.8%	78.8%
no change	17.5%	28.6%	28.4%	10.9%	46.2%	18.6%
less time/labor	74.7%	51.4%	5.2%	0.0	0.0	2.6%
	100 %	100 %	100 %	100 %	100 %	100 %
Ease of Use						
very difficult	2.6%	20.6%	19.0%	54.0%	33.3%	63.9%
moderate	22.2%	29.4%	36.2%	36.5%	33.4%	25.8%
very easy	75.2%	50.0%	44.8%	9.5%	33.3%	10.3%
	100 %	100 %	100 %	100 %	100 %	100 %
Compatibility						
not compatible	3.9%	28.6%	11.2%	63.9%	18.5%	66.5%
moderately compatible	15.6%	28.5%	25.9%	24.6%	33.4%	21.2%
very compatible	80.5%	42.9%	62.9%	11.5%	48.1%	12.3%
	100 %	100 %	100 %	100 %	100 %	100 %
Influence on Soil Erosion						
worsened	1.4%	0.0	1.8%	0.0	0.0	0.0
no change	16.8%	50.0%	27.0%	61.0%	12.5%	45.0%
improved	81.8%	50.0%	71.2%	39.0%	87.5%	55.0%
	100 %	100 %	100 %	100 %	100 %	100 %

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[1] Scale categories: Respondents were asked to evaluate BMP characteristics on a 11 point scale. For this analysis they were collapsed into 3 categories; 1-4, 5-7, and 8-11.

TABLE3 : Most Important Source of Soil Conservation Information by Use of Conservation Practices

USE	SOURCES OF INFORMATION (Percent of Total, N= 185)				
	Friends and Relatives	TV, Radio, and Print Media	Farm Supply Dealers	Farmer Organizations	Government Agencies
Currently Using 1 or 2 Practices	13.6%	9.1%	13.6%	4.5%	59.1%
Currently Using 3 or 4 Practices	17.8%	14.3%	3.6%	7.1%	57.1%
Currently Using 5 to 8 Practices	0.0	15.0%	5.0%	0.0	80.0%

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Background Paper No. 26

DATA AVAILABILITY FOR THE ASSESSMENT OF TECHNOLOGIES AND PUBLIC POLICIES RELATING TO AGRICULTURAL PRODUCTIVITY

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U.S. Congress

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1. INTRODUCTION AND SCOPE

1.1 PURPOSE OF THIS PAPER

The purpose of this paper is to assess the scientific data base relating agricultural technologies to land productivity. Productivity will be viewed from a long-term national policy perspective. This long-term public viewpoint means that data and methods of analysis will be discussed which pertain to the mantenance of the resource base rather than data and methods used to forecast yields. In this sense the productivity of the soil is seen as a collective resource, spanning generations and providing "goods" for the society at large even though cropland may be "owned" by specific individuals. Chapter 1 will further elaborate on the scope and viewpoint of this paper.

Chapter 2 is devoted to the basic elements that determine agricultural productivity and how these interact. By means of the relationships thus defined, some characteristics of an agricultural policy decision model will be discussed.

Chapter 3 describes various attributes of the data avilable for each one of the major causal linkages of the conceptual model of Chapter 2. The consequences of missing data and of missing feedbacks from the physical to the socioeconomic system will be qualitatively assessed.

Chapter 4 summarizes the state of the art in policy modeling where considerations of agricultural productivity are concerned. The attributes of several current policy models are contrasted with the desired characteristics of a useful policy model described in Chapter 2.

Conclusions about the status of the data base and existing policy models will be summarized in Chapter 5. Recommendations are made regarding the contribution modeling can make to national policy formulation and the need for a data base to support this effort. Suggestions are made about the highest priority tasks to be addressed with a state-of-the-art policy modeling technology.

The information base for this paper was originally intended to be a series of ten individual studies commissioned by the Office of Technology Assessment (OTA), dealing with the impact of sets of technologies on soil productivity. These studies have been used in general support of the sections discussing physical interactions and the impact of individual technologies on various parts of the natural system. What was lacking, however, were discussions of how the physical and economic systems interact and how soil productivity fits into the socioeconomic decision system of the farmer. The OTA studies also contained little information on recent data collection and policy modeling efforts. The OTA papers thus had to be supplemented with a range of papers beyond the original ten commissioned papers and by conversations with twenty-one poeple presently involved in developing models and data bases in agricultural experiment stations and universities across the United States.

1.2 PRODUCTIVITY DEFINED

For the purpose of this paper, productivity will be defined as the share of land as a factor of production in total agricultural output. In this sense cropland is considered a renewable resource base, composed of the soil, soil nutrients, organic matter and whatever micro and macro fauna and flora inhabit the soil layer or make up the soil ecology. To this will be added groundwater resources, although with lesser emphasis, since they too are natural resources and contribute to the intrinsic productivity of cropland.

Certainly agricultural production on any one parcel of land can be increased by the application of fertilizers, pesticides, capital, management and seed genetics. Total agricultural production and the most efficient mix of factor inputs is, however, a private issue concerning the individual farmers. The public issue is whether the natural resource base, the soil and groundwater to which technologies are being applied, is being maintained. This resource base is, partially, a public collective good and thus a proper subject for public concern. Thus productivity in this paper will be used to mean the "intrinsic productivity" of the soil and water natural resources. Leaving all the fertilizer, pesticide, management practices and capital equipment outside the definition allows us to then pose the question of what effect these "outside" influences have on the soil and water natural resource base.

In economic terms, land and groundwater are factors of production with inelastic supply surves -- there is an absolute limit to the amount of land and water of any given quality available, regardless of the need for agricultual output. In a sense, land is the basic production factor and all the other "exogenous factors of production" -- the technologies and management -- are applied to derive marginal increases in yield.

Yield is the total output, per unit of land, resulting from all of these factors of production and is the quantity usually cited in discussions of agricultural production (United States Department of Agriculture, 1980a) Yield is easily measurable as the quotient of output divided by land area, whereas changes in intrinsic productivity can only be deduced by well-designed experiments in which all technological inputs including seed varieties and weather are controlled. Thus the major difficulty with this study is that the primary focus, intrinsic productivity, is "disguised" by a plethora of other factor inputs and has not been the object of investigation at experiment stations for many years.

1.3 REASONS FOR PUBLIC CONCERN

Concern over the productivity of the agricultural resource base is rooted in recent reports of alarming topsoil erosion rates, the abandonment of soil conservation management practices, the attempt to bring into production ever more marginal and fragile croplands, the realization that the best "prime" farmland is diminishing at an accelerating pace due to urban sprawl, the fact that the ever-increasing levels of fertilizer and pesticide inputs are suddenly becoming much more expensive due to oil price increases and environmental regulations and the realization that yields are not responding to these increased input levels.

A parallel set of trends can be found concerning much of our nation's groundwater resources that underlie a large fraction of the most productive farmland. Here concern is initiated by the enormous increase in pumping costs occasioned by drawdowns in the water table, the real and potential impact of groundwater pollution from agricultural chemicals and the voracious need for flushing water to keep croplands from being destroyed by increasing levels of salt concentration. Thus there is physical evidence that both the soil and water renewable resource bases are deteriorating.

A major concern about soil and water resources stems from the realization that they will play an increasing role in America's economic future, domesticly and internationally. World appetite for U.S. grain exports has occasioned a tremendous increase in crop prices - the prices of some commodities have doubled in the last two years. Agricultural exports are perceived as a major foreign exchange earner to offset the increased price of imported oil and represent a long-term comparative advantage of the United States relative to all but two or three other countries in the world.

While the need for agricultural production has caused groundwater resources to become highly valued for agriculture, the expansion of coal mining and processing in the west will be a strong competitor for scarce water supplies. Just as the nation looks to agriculture to bolster the national foreign exchange deficit, so it looks to coal, synfuels and minemouth generation to supply an increasing share of domestic energy needs in addition to exports. Both of these national priorities seek to expand their share of limited water resources. The allocation of groundwater and farmland resources in a manner that will promote the greatest long-term welfare of society is an important and urgent public policy issue. The answer will be greatly influenced by what we can learn about the productivity of croplands and how this productivity is expected to change as a result of agricultural technologies.

Preservation of the public interest in land and water resources ranks among one of the hardest public policy problems of this for several reasons. The first is ownership. Even though there is a clear need to manage soil and water resources for the long-term good of society, the fact of private land ownership and private water rights limits the extent to which society can influence how these resources are managed and what technologies are used.

Second is the discrepancy between private and social time horizons. Individual farmers operate in the market environment, and use current discount rates to weight the merits of long- versus short-term benefits. This often means that technologies and management practices that result in benefits for future generations but which involve immediate costs will be implemented by the individual at less than the socially optimum rate.

Third, many agricultural technologies, especially chemical pesticides and fertilizers, have pollution externalities, or costs, that are borne by the society at large and not reimbursed by the individual who causes the pollution. The reasons for this are that it is physically very difficult to establish which pollution impact resulted from a particular activity. Even when the health or environmental impacts are known, it is hard to assign a monetary cost to these "unquantifiable" impacts and even harder to arrange to compensate the pollution victims.

Finally there is an element of irreversability about losses in soil productivity. Although both soil and groundwater resources are theoretically "renewable", the recovery time needed to build up topsoil from completely eroded land is practically very long, the expenditure required to reclaim salinated soils is huge, and the time it would take for large "fossil" aquifers to flush out pollution loads is enormous. This means that the public must not only be concerned with real threats to these collective resources but the possible degradation that may occur from new technologies about which information is incomplete. This irreversibility implies that policies should be implemented to preserve the resource even if the net social benefits are negative now. Not to do so would preclude the opportunity of benefiting from these resources in the event that social values change in the future.

A useful public policy model must therefore include socioeconomic linkages connecting the state of the resource base to the use rate of agricultural technologies in addition to the determinants of physical productivity. The importance of data for models depends on how necessary it is to deal with the four generic resource management issues noted above.

1.4 AGRICULTURAL TECHNOLOGIES AND MANAGEMENT PRACTICES

For the purpose of this paper, agricultural technologies will be defined in general terms such as products that are applied to the soil and crops, the machinery that is used on the land and the way in which products and machinery are used. Not included for assessment here will be such things as farmer cooperatives or marketing strategies since, although they may marginally affect the type and amount of crops produced, this effect is in no way generic to their use, and the effect will only marginally impact soil intrinsic productivity.

Table 1 shows the type of technologies to be investigated. Note that some of the technologies may imply the use of other technologies, as in the case of no-till farming generally being used with herbicide applications or the use of eight-row farm equipment precluding the use of old erosion prevention terraces and contours designed for four-row equipment. There are many such interlinkages among technologies.

1.5 PUBLIC POLICIES AFFECTING TECHNOLOGY USE

Although it is not the purpose of this paper to evaluate the impact of public policies on land productivity, one must know the general types of public policies that may eventually be evaluated in order to include the requisite information in the data base assessment. Table 2 shows a list of some fairly general public policies or programs which range from regulations to economic incentives. Note that a few of these impact

Table 1

AGRICULTURAL TECHNOLOGIES AND MANAGEMENT PRACTICES

PRODUCTS

- Chemical Fertilizers
- Insecticides and Nematocides
- Fungicides
- Herbicides
- Lime
- Biological Pesticides
- Improved Seed Varieties

MACHINERY

- Heavier Farm Equipment
- Six- or Eight-Row Farm Equipment
- Mechanical Tree Harvesters

MANAGEMENT PRACTICES

- No-Till Cropping, Complete Removal
- Groundwater Irrigation and Drainage
- Contour Farming and Terracing
- Increased Farm Size
- Pesticide Rotation
- Crop Rotation, Yearly and Seasonal
- Fall Plowing
- Use of Fence and Hedgerow Windbreaks between Fields
- Field Spreading of Manure and organic wastes

Table 2

SOME GENERAL PUBLIC POLICIES THAT AFFECT THE USE OF AGRICULTURAL TECHNOLOGIES

REGULATIONS

- Pesticide use, testing and marketing regulations
- Groundwater use regulations
- Limitations on converstion of prime farmland to urban uses

INFORMATION DISEMINATION

- Government R&D on technologies such as biological pesticides
- Agricultural extension service training in conservation practices, biological pesticides, productivity impacts of technologies, fertilizer and pesticide response, soil testing

ECONOMIC INCENTIVES

- Incentives for erosion control investment and maintenance
- Taxes on biomass harvesting for energy production from cropland
- Loan or mortgage policies for land or equipment purchase
- Incentives for small-scale farm operations which effectively increase landscape diversity
- Incentives to increase organic waste material recycling to croplands
- Groundwater pricing policies for nonagricultural use
- Crop price floors or subsidies
- Real estate taxes and agricultural differentials

directly on the use of particular technologies like pesticide regulations on pesticide use. Some of the education programs are aimed at increasing a farmer's awareness of the long-term consequences of technologies on productivities. Most of the policies do not impact the use of a specific piece of equipment but seek to promote management practices that minimize productivity declines. It must be noted that, by far, the greater emphasis in education programs has been on technologies and management to increase yields.

The policies in Table 2 may not be immediately implementable. They indicate that the conceptual model to be developed must include the proper causal linkages to show the impacts of these types of policies. Note that some policies could be designed to be triggered by some critical state of the physical system. They would thus serve as a feedback which would encourage remedial measures when soil productivity dropped below an acceptable level. It is not claimed that all or any of these policies will in fact be effective at maintaining or increasing productivity.

The data base question is therefore not whether information exists to evaluate whether or not these policies will work, but rather, under the assumption that these types of policies can be implemented, if tried, how will soil productivity be affected.

1.6 ELEMENTS OF THE CONCEPTUAL SYSTEM

The purpose of a conceptual schema or system is to define the major parts of the agricultural system for which we intend to assess data needs. To be useful, the system should explain in qualitative terms the mechanisms by which agricultural technologies and management practices affect productivity.

As an example, the conceptual system for this project must show how each of the following items interact to affect productivity.

- fertilizers,
- pesticides,
- soil chemical changes,
- microbiological activity,
- macrobiological activity,
- organic farming techniques,
- groundwater quality and quantity,
- soil compaction,
- ecological effects, and
- erosion.

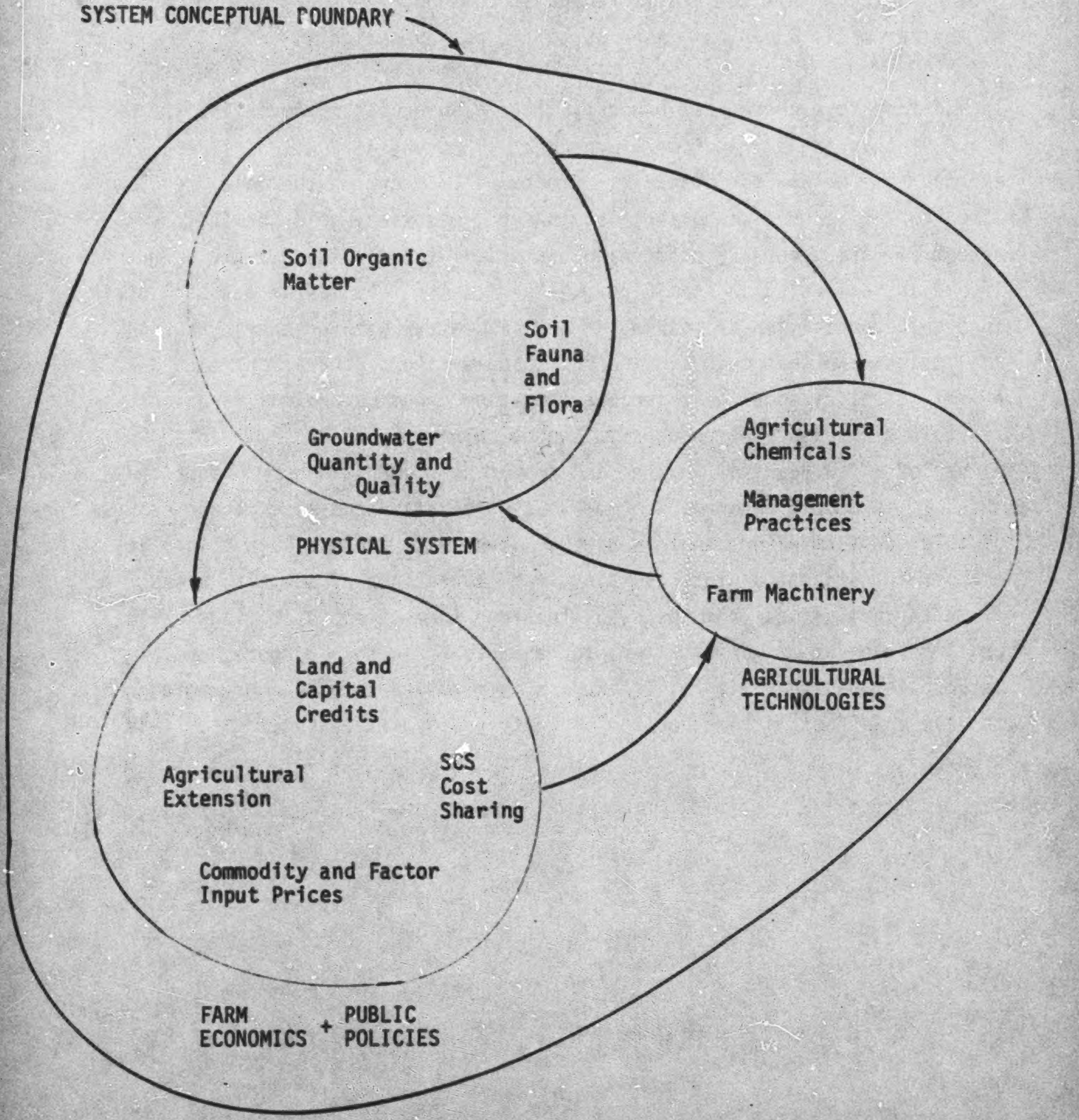
Some of the above are techniques, some are technologies and some are processes. The conceptual schema will show what the principle items are that determine productivity and how all the elements in the above list are related.

Intrinsic soil productivity is determined by soil tilth or structure, soil available nutrients, principally N, P, K, nitrogen fixation potential and the absence of toxic residues. Groundwater contributes to soil moisture and is a vehicle for transport of nutrients and pollutants. While not technically a part of productivity, it contributes to soil usability and maintenance. Soil tilth and nutrient availability result primarily from such things as the level of soil organic matter and how it is transformed by microbiological, erosive and tillage practices, how microbial activity is affected by agricultural chemicals and water quality and how water quality and quantity are in turn affected by management practices.

An extremely simplified diagram showing these fundamental elements and illustrating the relationship between the physical system surrounding the resource base, the management and technologies that impact on this system and public policies that affect the use of technologies is shown in Figure 1. Note that data availability will be assessed for those items within the system boundary. All else is beyond the scope of this paper.

Figure 1

A SCHEMATIC DIAGRAM ILLUSTRATING THE PHYSICAL, TECHNOLOGICAL AND PUBLIC POLICY INTERACTIONS WITHIN THE CONCEPTUAL SYSTEM BOUNDARY


SYSTEM CONCEPTUAL BOUNDARY
Soil Organic Matter
Soil Fauna and Flora
Groundwater Quantity and Quality
PHYSICAL SYSTEM
Agricultural Chemicals
Management Practices
Farm Machinery
AGRICULTURAL TECHNOLOGIES
Land and Capital Credits
Agricultural Extension
SCS Cost Sharing
Commodity and Factor Input Prices
FARM ECONOMICS + PUBLIC POLICIES

Note that, whereas it is apparent that technologies affect the physical system, it is not yet clear to what extent changes in the physical system serve to change agricultural practices. Also, public policies may to some extent affect technology use such as conservation practices, but it is not obvious how effectively changes in the physical system get translated into public policy. Thus the existance and strength of the relationships shown by the arrows is a central issue in public policy design.

In addition to a conceptual boundary it is also necessary to define the scope of this inquiry in time dimensions. The type of public policies and the time delays for observing effects will determine the most useful time horizon. The time horizon is, in turn, necessary to determine the extent of data necessary concerning historical trends, for example. Thus if one is interested in examining public policies that may affect soil depth through decomposition and mixing of organic matter with weathering subsoils and it is known that such significant changes take a generation, then an efficient policy model must include long-term dynamics and not focus on day-to-day changes. Although soil can be physically eroded away in a manner of a few years if weather and topographic conditions are right and the soil is poorly managed, we hope to assess data needs to evaluate changes of a longer term nature in this paper. These will include such things as changes in nutrient cycles resulting from adaptations of soil fauna and flora to agricultural chemicals, or the long-term effect of tillage practices on soil organic matter, for example. For this purpose, and because any public policy will take a number of years to be implemented and to have an affect, a time horizon of fifty years will be assumed for this study.

2. SYSTEM INTERACTIONS

2.1 SOIL PRODUCTIVITY

Soil productivity is the result of numerous chemical, physical and biological processes, which proceed at different rates depending on the climatic regime, topography, and basic soil class. All of these processes are affected by one or more agricultural technologies and indeed the magnitude of these technological impacts depends in turn on the geographic and climatic specifics of soil location. Figure 2 schematically shows the components of soil productivity and how they are causally related, with the item at the tail of the arrow causing a change in the item at the head of the arrow.

Soil productivity is increased by the plant-available (inorganic) nitrogen (n) phosphorus (p) and potassium (K) in the soil. These nutrients result from the biological decomposition of organic matter by the soil microbial population. The chemical changes that transform organic matter to plant-available nitrogen and the contribution of fertilizers relative to the naturally occurring nitrogen level are described by Mengel (1980) and Winteringham (1979). The role of organic matter in soil physical and chemical properties is described by Welch (1980). As decomposition proceeds, however, this draws down the level of organic matter. Thus the "feedback loop" shown by the arrows linking decomposition rate to soil organic matter is "self limiting." For a given level of soil microorganisms, all else equal, increases in organic matter tend to speed the rate of decomposition and this decreases the level of organic matter available. One of the primary effects of plowing is to increase the organic materials available to microorganisms and thus increase the rate at which decomposition proceeds.

The total rate of soil formation depends upon the rate of weathering of the subsoil layer as this is mixed with a net accumulation of organic matter. Conservation policies are often designed on the basis of reducing erosion rates low enough so that the rate of soil loss is no greater than the rate of soil formation. This rate is called a "tolerance level" or T value

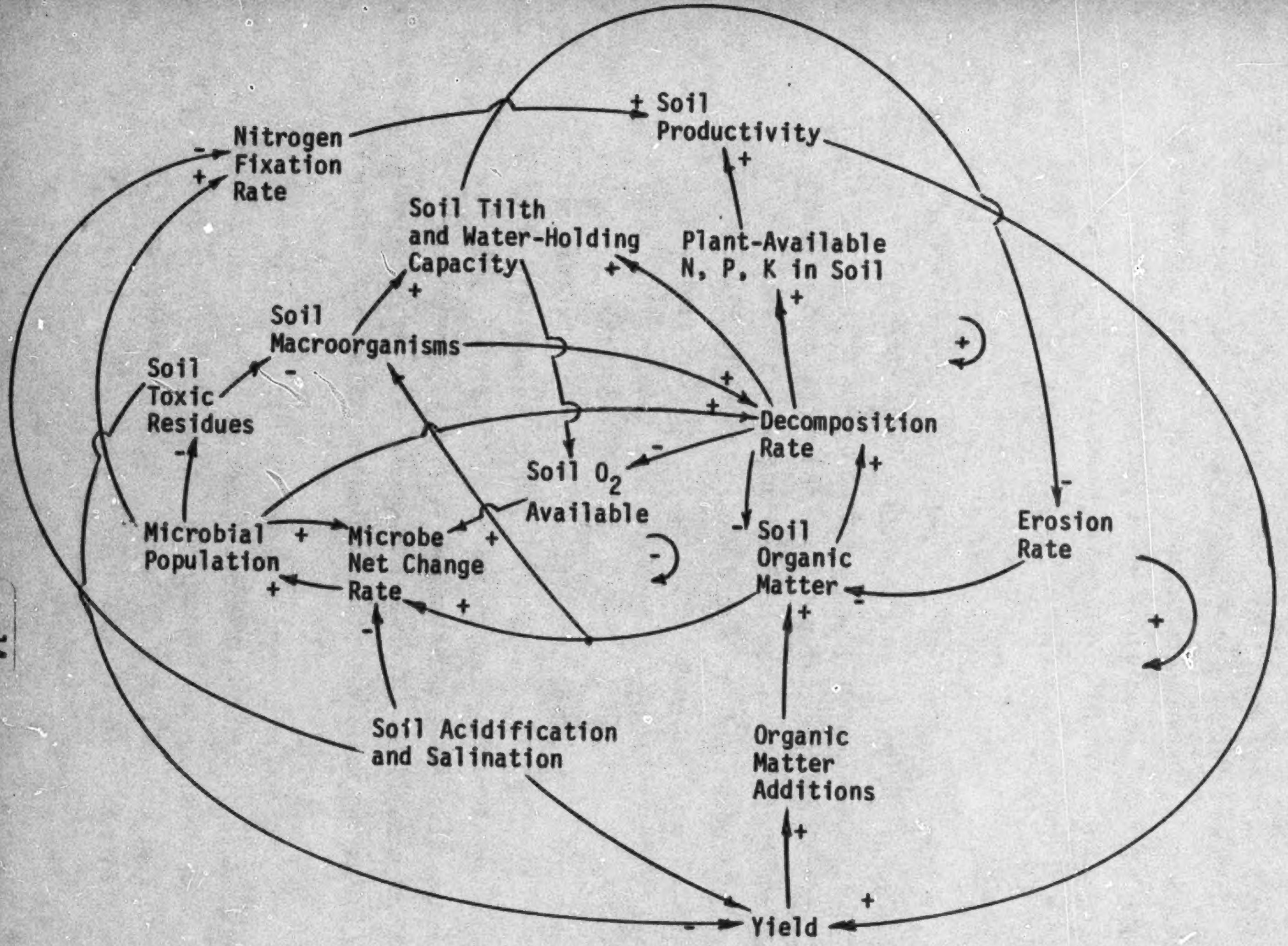

Nitrogen Fixation Rate
Soil Productivity
Soil Tilth and Water-Holding Capacity
Plant-Available N, P, K in Soil
Soil Macroorganisms
Soil Toxic Residues
Decomposition Rate
Soil O$_2$ Available
Microbial Population
Microbe Net Change Rate
Soil Organic Matter
Erosion Rate
Soil Acidification and Salination
Organic Matter Additions
Yield

Figure 2

SOME OF THE BASIC CAUSAL LINKAGES
WHICH DETERMINE SOIL PRODUCTIVITY

for erosion losses. Whereas a level of five tons per acre per year has generally been accepted by policy analysts in recent years for all soils in all parts of the United States, there is agreement that each soil-climate regime has a unique T value as well as widespread speculation that realistic T values may be closer to 0.5 tons per acre per year (Larsen, 1980; McCormack and Larsen, 1980).

Soil organic matter is increased by organic matter additions to the soil which result from crop residues and root excretions. Such additions are directly proportional to the yield per acre, but the extent to which yield increases result in organic matter additions depends on the tillage and residue management practice employed. Yield will increase as a result of many inputs such as fertilizers and, of course, increases in the soil productivity itself. The mechanisms just described result in a "positive feedback loop" linking soil productivity and yields. As productivity rises, yields also rise and cause a chain of events that eventually results in even higher productivity. This process is denoted by a positive sign within the loop in Figure 2, and would continue indefinitely in the absence of erosion and nutrient leaching, resulting in increasing accumulations of organic matter. Eventually, however, both productivity and yields respond in a "decreasing returns to scale" fashion to continued increments in factors which cause them to increase.

Both wind and water erosion remove topsoil layers and thereby reduce the amount of soil organic matter available for decomposition. Soil erosion removes the uppermost organic layers first, resulting in an exponential decay of soil nitrogen which proceeds as long as the soil is cultivated (Welch, 1980). In fact the soil nitrogen is in dynamic equilibrium with erosion and harvest losses counterbalanced by soil formation and fertilizer imports (Winteringham, 1979).

The decomposition of organic matter in the soil by both micro and macro organisms results in soil structure or "tilth." Soil tilth is partly a result of chemical changes that occur during microbial decomposition that produce soil aggregates and the action of soil macro-organisms which produce castings and aerate the soil mechanically. These processes produce soil with a greater water holding capacity and increase the water permeability of soil while at the same time increasing the ease with which roots and oxygen can penetrate the soil. Soil tilth then acts to decrease the erosive effects of wind and rain. Thus the causal linkages from the erosion rate acting through soil organic matter and tilth and returning back to erosion rate form a positive feedback loop. The implications of this are that erosion, once begun, tends to cause changes in the soil physical system that further increase the severity of erosion in the future. An excellent review of the role of soil tilth in productivity is given by Shrader, (1980).

The level of organic matter in the soil is linked to the microbial population through two causal mechanisms. First, increases in the organic matter content of the soil increase the number of soil micro-organisms since more organic nutrients are available. Changes in the species composition of the microbial population also occur due to nutrient changes and a host of other factors. The details of these dynamics are reviewed in Alexander (1980). The microbial population increases and thus increases the decomposition rate which in turn, reduces the soil organic matter. This is a negative feedback loop which means that the level of the microbial population and the level of soil organic matter are continually adjusting relative to one another-increases in one cause increases in the other and vice versa. The rate of adjustment of the microbial population to changes in soil organic matter is controlled, in part, by the level of available soil oxygen. Increases in the decomposition rate reduce the level of soil O_2 which tends to retard growth in the microbial population, and thus slow the rate of decomposition (Alexander, 1980). This, too, is a negative feedback or control loop.

Soil intrinsic productivity has at least three important components: 1) the levels of N, P and K available to higher plants; 2) the soil structure, or tilth; and 3) the nitrogen fixation and nitrification potential of the indigenous microbial population. A fourth attribute of productivity may be the absence of toxic residues such as pesticides and heavy metals. These have been shown in Figure 2 as affecting yields, however, such toxics may be more of a factor in the marketability of the crop when incorporated into plant biomass than the plant's ability to grow. The nitrogen fixation rate (the rate at which atmospheric N_2 is converted to plant-available nitrates) depends upon not only the level of microbial population, but the species composition and the crops grown. This has been simplified in Figure 2. Indeed species composition effects are complex, depending on a host of site-specific parameters. Agricultural technologies may have effects on species composition, however, little can be said of a consistent nature about the linkages between technologies, species mix and productivity.

Soil tilth, or structure, is a result of both microbial action and the physical and chemical actions of soil macro-organisms. To a degree, toxic residues, which also include undegraded pesticides, inhibit or destroy the macrobiotic community until these organic chemicals are broken down by the microbial population (Alexander, 1980). Thus the service of organic chemical degradation provided by the microbial population has a beneficial effect on soil fauna, which increase soil tilth and organic matter decomposition, as well as on yields. Toxic residues may also be instrumental in chancing the species composition of the microbial population and thus affecting such services as nitrogen fixation and nitrification, or they may pollute groundwater systems, but the results of tests that have been done on such effects are not generalizable to wide ranges of soil and climate conditions, so these linkages have been left out of Figure 2. The effects of pesticide use on crop yield, the lack of experimental evidence for the environmental effects of pesticides now in use, the lack of coordinated pesticide monitoring activities and an indication of the externalities associated with pesticide use are discussed in Harkin _et al_ (1980)

Soil acidity and salt content both decrease the ability of soil microorganisms to reproduce and provide beneficial services as well as directly inhibiting plant yields. Acidity and salt content are increased by the application of inorganic fertilizers and by irrigation under conditions of high evapotranspiration and poor drainage.

In summary, soil productivity can be conceptualized as one of the endogenous system elements that affects crop yield, along with a host of exogenous technology inputs to the soil fertility system not shown in Figure 2. Intrinsic soil productivity is a function of plant available nutrients, soil tilth, and the presence of soil fauna and flora that are capable of maintaining the essential biogeochemical nutrient cycles.

The soil fertility system is conceptualized as a dynamic system which includes many feedback processes that regulate the levels of soil organic matter, soil micro- and macro-organisms in response to environmental conditions and technological and management inputs. The most important feedback processes that have been reviewed include:

- the loop linking productivity and yield through organic matter and decomposition;
- The loop linking soil tilth and erosion through organic matter and soil micro- and macro-organisms; and
- the loops linking the decomposition rate to the level of soil microbial populations through soil available O_2 and soil organic matter levels.

2.2 GROUNDWATER RESOURCES

Today approximately 16 percent of the nation's cropland is irrigated. The amount of irrigated cropland has increased by 36 percent in the last 22 years. Agricultural irrigation accounts for nearly two-thirds of all the groundwater used in the United States and this groundwater represents almost a quarter of the total water consumed. It is evident that the quantity and quality of groundwater resources are becoming increasingly important for the maintenance of total agricultural productivity. Evidence is mounting of groundwater depletion and the consequent reduction in agricultural yields (Walsh, 1980). Groundwater represents a renewable resource which, like soil productivity, is subject to technological impacts and suffers from many of the same generic problems and conflicts of management for the public good described in Section 1.3 for soil resources. Yields are intimately tied to the quantity and quality of groundwater resources in much of the highly productive western croplands. These groundwater resources are somewhat area-specific. The sustained yield of groundwater, like land (and soil) is inelastic. These are all reasons for considering groundwater resource quantity and quality as part of the intrinsic natural resource base, apart from other exogenous factor inputs that combine to determine yields.

Some of the major causal linkages that determine groundwater quantity and quality are shown schmatically in Figure 3. Since the analysis of any given aquifer will depend upon site-specific concerns such as the recharge rate, surface seepage, indigenous agricultural and industrial activities and so on, Figure 3 attempts to capture only the most important generic processes at work. Discussions of the linkages between agricultural technologies, water use and the hydrologic system are found in Vanlier (1980) and Lehr (1980).

The amount of water in an underground aquifer is increased by the recharge rate and decreased by water extraction. In "fossil" aquifers the recharge rate is small compared to the overall volume of water. When it is small compared to the actual rate of withdrawals, then the aquifer is being "mined." Groundwater mining becomes a problem when withdrawals are large compared to the aquifer volume and the depth of the water table (below ground level) increases. Increasing well depth increases the pumping costs of irrigation and contributes to land subsidence, well casing breakage, and the maintenance cost of irrigation. Land subsidence can also alter streamflow and aquifer recharge, although the effects of this are so site-specific that they haven't been included in Figure 3. Increased irrigation water costs,

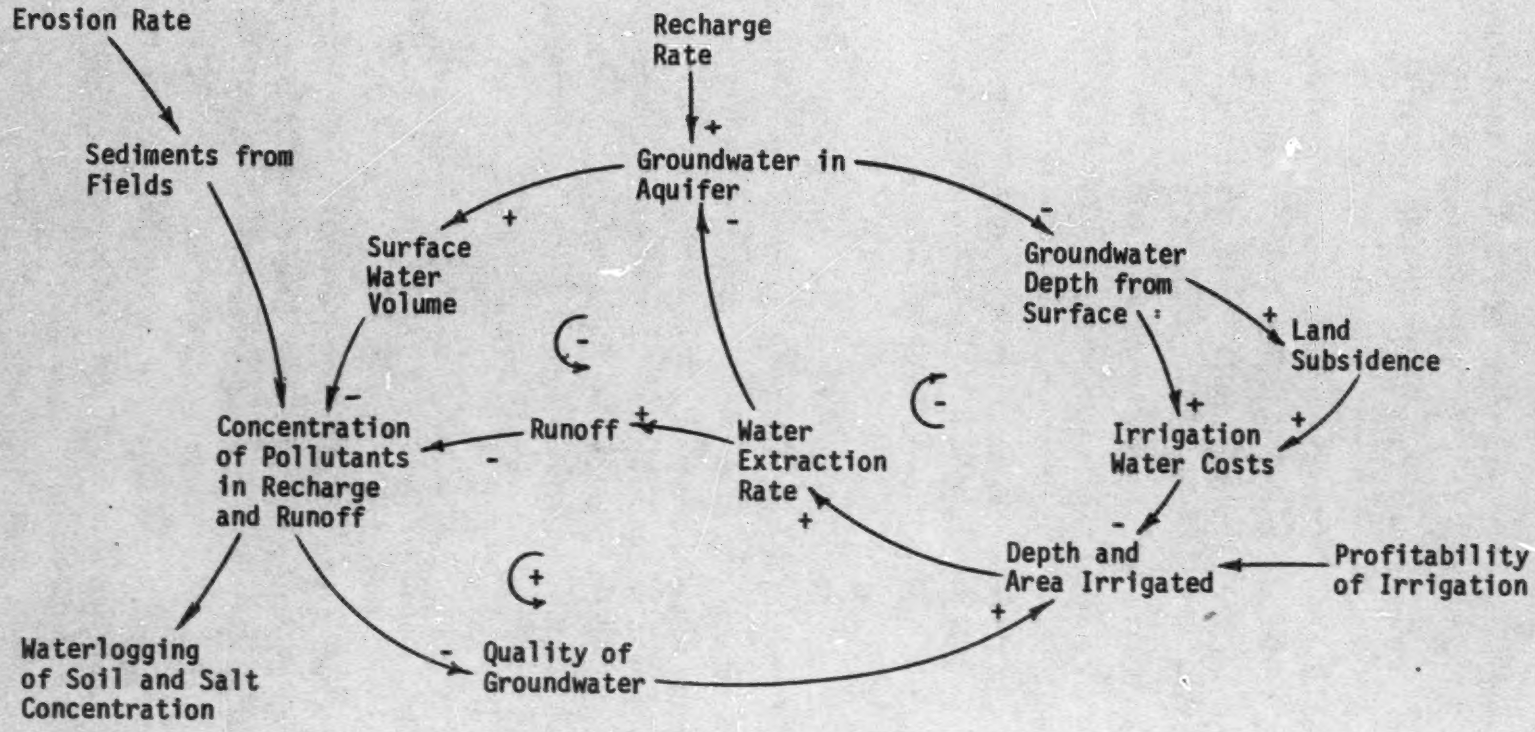

Erosion Rate
Sediments from Fields
Recharge Rate
+
Groundwater in Aquifer
+
-
-
Surface Water Volume
Groundwater Depth from Surface
+
Land Subsidence
-
Concentration of Pollutants in Recharge and Runoff
Runoff
+
-
Water Extraction Rate
+
Irrigation Water Costs
+
+
-
Depth and Area Irrigated
Profitability of Irrigation
Waterlogging of Soil and Salt Concentration
-
Quality of Groundwater
+
-
-
+

Figure 3

SOME OF THE CAUSAL LINKAGES WHICH DETERMINE GROUNDWATER QUALITY AND QUANTITY when compared to the returns to irrigation (based upon market prices, etc.) tend to result in decreased application of irrigation water on particular parcels and eventually a reversion to dry-land cropping patterns. Decreased irrigated acreage results in less water extraction and, eventually more water in the aquifer. The feedback loop just described is thus a negative control loop that tends to reduce water withdrawals as groundwater mining proceeds, but only through the action of progressively higher costs of irrigation. Calling this a control loop does not mean that groundwater mining will cease before the aquifer runs dry to agriculture is driven out. Irrigation costs may not increase fast enough in a "free market" situation.

Groundwater quality is influenced principally by the concentration of salts, fertilizer (nitrogen) and other chemical pollutants. This concentration increases as the volume of runoff from cultivated fields decreases, assuming the same level of chemical application, and as the total volume of receiving waters decreases. Figure 3 shows that surface water volume decreases as groundwater volume decreases, to the extent that surface waters are augmented by groundwater seepage. Also, runoff is proportional to the application rate of irrigation water, or the extraction rate. In the special case of freshwater lenses overlying aquifers of high salt concentration, groundwater overdrafts can result directly in salt water intrusion. Degradation in groundwater quality is another factor which will cause the area and intensity of irrigation to decrease.

In summary, groundwater quantity and quality is seen as an important part of the intrinsic soil productivity problem to the extent that groundwater suffers from the same management problems and exhibits inelastic supply relative to the overlying soil resources. When groundwater is being exploited in the "mining" mode, two negative feedback loops control the extraction rate. One of these relates extration to the increasingly disadvantageous economics of ever-deeper irrigation wells and absolute quantity shortage. The other relates aquifer water volume to the increased concentration of pollutants from agricultural chemical runoff and saline water intrusion.

2.3 SOIL-GROUNDWATER INTERACTIONS

Granted that groundwater resources are an integral determinant of yields for irrigated crops, what is the relationship between the elements of the groundwater system, shown in Figure 3 and the soil productivity system shown in Figure 2? Figure 4 shows some of the major interactions between groundwater quantity and quality and soil productivity. Some of the linkages between the agricultural and groundwater systems are reviewed in Todd (1980).

Increased concentrations of salts and toxic residues in irrigation water are shown in Figure 4 to decrease soil tilth, principally through chemical reactions, or "waterlogging" that reduces water permeability and leads to incrustation and decreased friability. The consequences of decreased soil tilth can be seen from Figure 2.

At the same time increased salt concentrations decrease the microbial activity resulting in reduced rates of nitrogen fixation and nitrification with the consequent reduction of plant available nutrients (Alexander, 1980). Finally increased salts and toxic chemical buildup can directly reduce yields. All three of the above impacts of pollution concentration eventually have an adverse effect on soil productivity which, as seen from Figure 2, directly decreases crop yields.

Crop yield decreases result in direct reductions in the profitability of irrigation, and this further acts to reduce the rate of groundwater extraction due to the negative feedback loop relating irrigation costs to the extent and intensity of irrigation.

Finally, the absolute quantity of water needed is a function of soil tilth, or the water-holding capacity of the soil. As tilth increases, extraction rates decrease and the absolute level of water in the aquifer is preserved. At a future time this greater groundwater resource will result in greater water availability for irrigation and hence increased yields. The increased yields offer the potential for increasing soil tilth, under appropriate management practices, as shown in Figure 2.

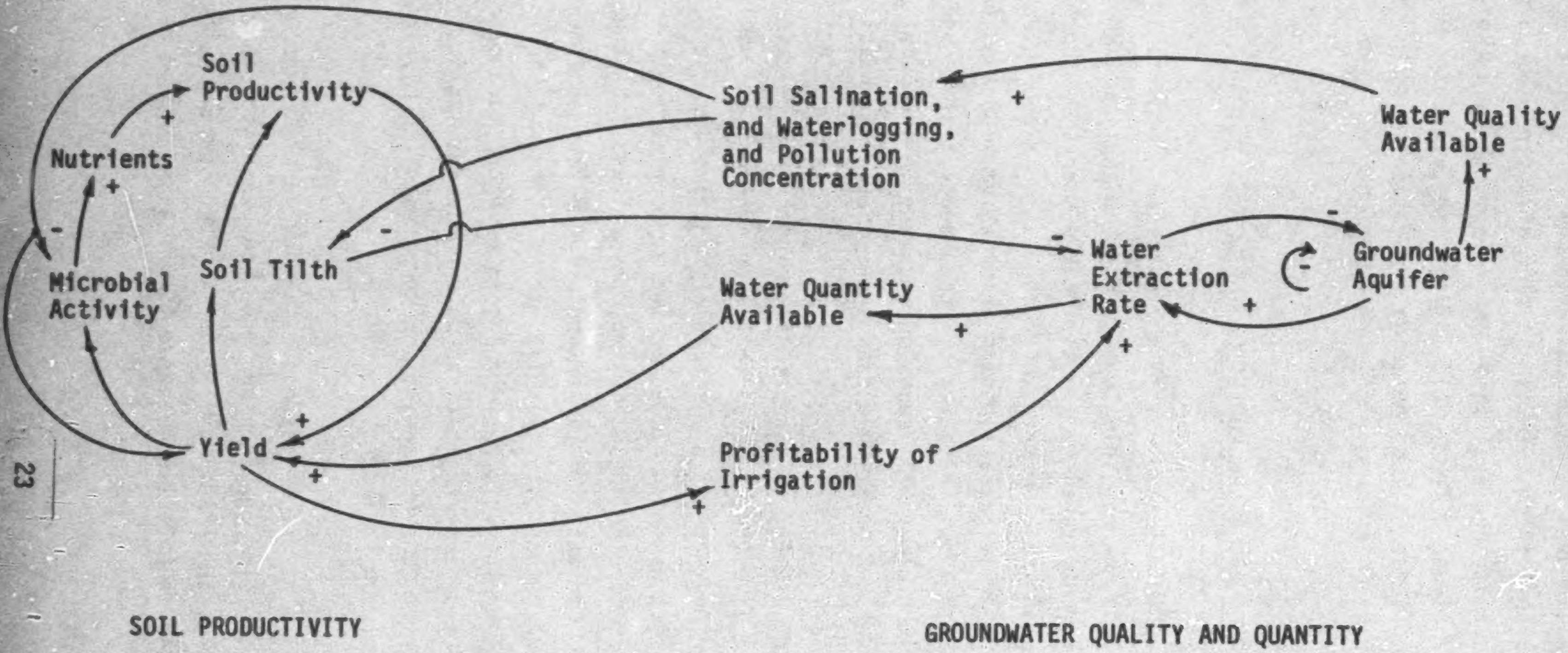

Soil Productivity
Nutrients
Microbial Activity
Soil Tilth
Yield
Soil Salination, and Waterlogging, and Pollution Concentration
Water Quantity Available
Profitability of Irrigation
Water Extraction Rate
Groundwater Aquifer
Water Quality Available
+
-
SOIL PRODUCTIVITY
GROUNDWATER QUALITY AND QUANTITY

Figure 4

MAJOR CAUSAL LINKAGES BETWEEN SOIL PRODUCTIVITY
AND GROUNDWATER QUANTITY AND QUALITY

In summary, groundwater quality interacts with the soil productivity system by impacting soil tilth, yields and microbial (and macrobial) activity. Water quantity and soil tilth are related through the amount of irrigation water needed. Crop yields affect the extraction rate through the economic feedback loop relating irrigation costs and benefits to irrigation intensity.

2.4 IMPACT OF AGRICULTURAL TECHNOLOGIES ON THE SOIL PRODUCTIVITY SYSTEM

Having defined the physical, biological and chemical processes at work in Figures 2 and 3, it is now possible to show how the application of any one technology or management practice impacts these elements of the physical system. Table 3 is an impact matrix which shows, for a technology in a given column, whether it has a positive or negative impact on the system elements in each row. A positive impact means that an increase in the use of the technology will cause an increase in the level or rate of the system element. A negative impact means that an increase in the technology or practice will cause a decrease in the system element, or a change in the system element of the opposite sign. In some cases, the scientific evidence is either not sufficient or contradictory as to whether an impact exists or whether its a positive or negative impact. In such cases, a question mark has been placed in the appropriate cell. Also, where the causal mechanism for the impact may not be obvious, a hint has been placed in the cell. For example, larger and heavier farm equipment reduce soil O_2 and tilth through compaction. Finally, the last row of the matrix concerns the impact of the column technologies on other technologies, when, for example, the use of larger eight-row farm equipment implies the consequent decreased use of contour farming and terraces which have been constructed for four-row equipment.

Table 3 illustrates that the assessment of agricultural technologies cannot be done relative to yield impacts alone. A given technology may impact other parts of the system which may, in turn, impact productivity and yields in the same or opposite direction at some future time.

Table 3

AGRICULTURAL TECHNOLOGY IMPACT MATRIX

System Elements	Agricultural Technologies												
	Fertilizer	Chemical Pesticide	Lime	Biological Pesticides	Improved Seeds	Larger Equipment	No-Till Cropping	Groundwater Irrigation	Contouring Terracing	Windbreaks Hedgerows	Crop Rotation	Cover & Strip Crops	Manure Spreading
Figure 2: Soil Productivity													
Erosion					- Close Cropping	+ Compaction	-		- Water & Wind	- Wind		- Wind & Water	
Organic Matter							+					+ Green Manure Crops	+
Decomposition Rate	+ Sometimes		+										
Crop Yield	+	+		+	+			+			+ Legumes	- Low Yield Crops	
Soil O_2						- Compaction	+ Less Compaction	-					- Through Decomposition
Micro-organisms	+ Sometimes	-					+ Less Weather Stress	+ Water Availability			? Diversity		
Toxic Residue		+					+ Herbicides						
Macro-organisms		-					+ Less Weather Stress	?			? Diversity		?

Table 3 (Continued)
AGRICULTURAL TECHNOLOGY IMPACT MATRIX

System Elements	Agricultural Technologies												
	Fertilizer	Chemical Pesticide	Lime	Biological Pesticides	Improved Seeds	Larger Equipment	No-Till Cropping	Groundwater Irrigation	Contouring Terracing	Windbreaks Hedgerows	Crop Rotation	Cover & Strip Crops	Manure Spreading
Tilth			+			- Compaction	+ Less Compaction						+ Decomposition Products
Nitrogen Fixation	+ Sometimes	- Fungicides									+ Legumes	+ Legumes	
Acid & Salt Concentration	+		-					+ Salination					
Figure 3: Groundwater													
Salt + Toxic Sediment in Runoff	+	+					- Sediment Runoff	+	- Less Sediment		- Close Cover	- Runoff	
Water Extraction							- Less Evaporation	+		- Less Wind Drying	- Close Cover Rotations	- Cover Crops	
Associated Technology Changes					+ No Till	- Terracing	+ Herbicides		- Larger Equipment	- Larger Equipment	- Pesticides - Fertilizer	- Larger Equipment	

KEY:
+: indicates technology has a positive impact or tends to increase system element.
-: indicates technology has a negative impact or tends to decrease system element.
?: direction or existence of impact is unkown.

Table 3 also shows that the data necessary for the assessment of agricultiral technologies must include information about the impacts of each technology on each system element. Since the existance and magnitude of many impacts is site specific, depending on soil class, geography, climate, etc., the quantified impacts should be both representative and internally consistent. Practically, this will necessitate a less aggregate matrix with more detail in both the technology specification and the system processes specified.

Finally, it should be noted that Table 3 shows direct impacts only. Table 3 for example, shows that the direct effect of lime additions is to decrease soil acidity, whereas Figure 2 shows that decreased soil acidity stimulates both general microbial activity and nitrogen fixation in particular. Table 3 shows no impact of lime on microbial organisms because this impact operates through the causal mechanism of acidity reduction. Thus, if all the eventual impacts of all the technologies were shown in Table 3 most of the cells would be filled, but this would result in fairly little information about how the technologies enter the feedback system shown in Figure 2.

Descriptions of how each of the individual technologies affect the soil/groundwater system can be found among the commissioned project papers. For example, the correlates of soil erosion as expressed in the universal soil loss equation are found in Hudson (1971), while conservation tillage was reviewed by Todd (1980), fertilizers by Mengel (1980), wind erosion by Woodruff (1980), farm machinery and compaction by Voorhees, et al (1978), erosion control technologies by Massie (1980).

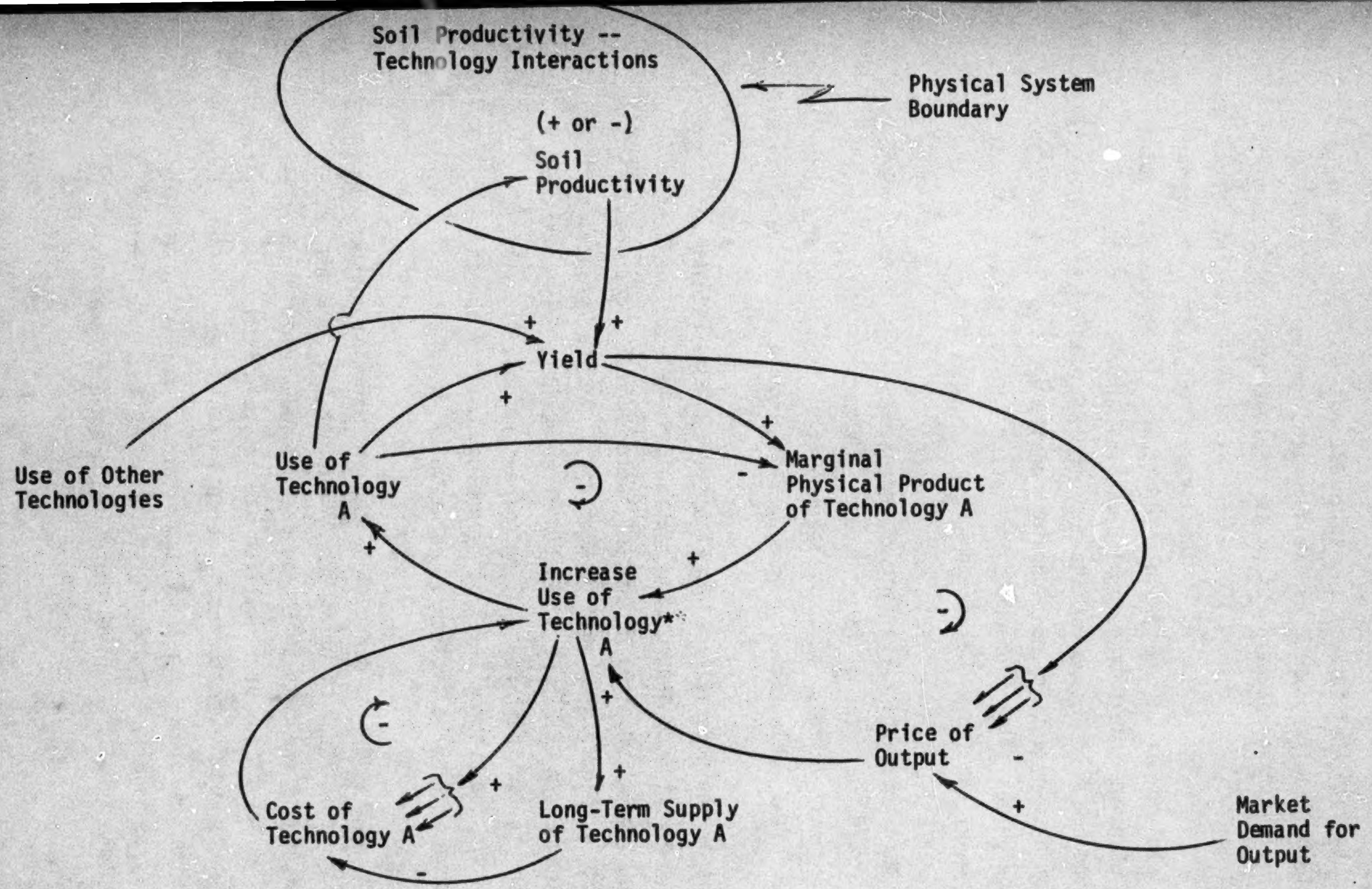
2.5 FACTORS AFFECTING TECHNOLOGY USE RATES

A complete analysis of the impacts of technologies on soil productivity must address the question of whether soil productivity impacts will be recognized by farm operators and whether such recognition will result in a change in the mix of agricultural inputs used on the farm. The short answer to the above question is, of course, no. Instrinsic soil productivity is not directly measurable, and so farmers, if they feel included to manage their farms according to productivity objectives can at best respond to such components as organic matter, soil tilth or nutrient levels, not really knowing the extent that these parameters have resulted from recent factor inputs and which are evidence of long-term productivity trends.

All farm operators observe yields, however, and every well-managed farm enterprise employs the amount of each production factor that will maximize profits for the current market situation. The feedback from the physical system is thus through current yields. Figure 5 shows schematically the interactions involved which determine the level of a given technology, or factor input, which is employed on a farm. The rationale behind the technology choice decision is economic -- the level and mix of factor inputs should be chosen so as to maximize farm profits. Furthermore, farm profits are maximized by employing each factor of production up to the point at which the revenues generated from the last increment of the input factor equal the cost of purchasing the input.

Figure 5 shows that the marginal physical product of a technology (or production factor A) decreases as the intensity of use of that factor increases. This is the standard behavior of decreasing returns to scale for production factors. The marginal revenue product is just the revenue that would be generated by an additional unit of input of the factor given the current market price for the product or crop. This marginal revenue is compared with the cost of the factor to see if "it pays" to increment the input. If so, the use of technology A is increased and yield is increased in response to the use of technology A.

The use of technology A then impacts the physical system through one of the system elements shown in Table 3 and then affects one or more of the feedback loops shown in Figures 2, 3 and 4. Finally, productivity changes result in yield changes. Figure 5 is thus a generic economic feedback system that applies to all the technologies shown in Table 3.


Soil Productivity -- Technology Interactions
Physical System Boundary
(+ or -)
Soil Productivity
+
+
Yield
+
+
Use of Other Technologies
Use of Technology A
-
Marginal Physical Product of Technology A
+
+
Increase Use of Technology* A
+
-
-
+
+
Cost of Technology A
Long-Term Supply of Technology A
-
Price of Output
-
+
Market Demand for Output

*Based upon the ratio of the marginal value product of technology A to the cost of technology A.

Figure 5

ECONOMIC FEEDBACKS WHICH DETERMINE THE USE RATE OF AGRICULTURAL TECHNOLOGIES

It is important to note that farmers themselves do not decide on the level of factor inputs by trial and error as was suggested above. Empirical determinations of the marginal products of available production factors are made at agricultural experiment stations or by factor-producing industries and this information is disseminated by the agricultural extension service and suppliers. In fact it is now possible for farmers to access sophisticated micro-economic planning models to determine marginal products, total yields, costs and net farm income via the computerized AGNET system, discussed below. One must also note that the technology choice decision is very much dependent on the prices of farm products and factor inputs, neither of which can be controlled by the individual farmer.

Figure 5 shows that the aggregate effect of increased yields in the marketplace is to decrease the price of farm outputs. The short-term aggregate effect of all farmers' demands for increased amount of technology A inputs is to raise the cost of this factor, assuming it is purchased in the market.

The implications of the generic model in Figure 5 for data requirements to assess technology impacts depend upon two factors. First, does the estimate of the marginal physical product of factor A really capture the long-term impacts of factor A on soil productivity? Second, granted that the allocation mechanism of Figure 5 results in an economically efficient mix of factor inputs for the farmer in the current period, does the mechanism result in the optimum level of technology use for the farmer over the long-term or for the society at any time?

Although Figure 5 may seem like a strictly economic optimization paradigm, it can encompass a wide range of behaviors. Consider the linkages between the use of technology A and both soil productivity and yield. Farmers can get information on the effect of fertilizer use on yield from the extension service, from AGNET, and manufacturers. The optimal use rate of technology A is then a straighforward calculation. The impact of technology A use on soil productivity is usually not considered, or if it is, it is assumed that no adverse impacts will occur or that impacts such as erosion will be acceptable (within the soil "tolerance limit").

Recent studies of farmers using a range of organic farming techniques have shown that perceptions of an undesirable causal link between the use of a set of technologies (pesticides and chemical fertilizers) as well as perceptions about the long-term trend in technology costs (fuel and fertilizer costs primarily) may lead to a wholly different set of factor inputs than are typical for conventional chemical-intensive agriculture (Phillips, et al 1980; Lockeretz, et al, 1981; USDA, 1980e; Carter, 1980). Organic farmers evidence a set of beliefs that intensive use of agricultural chemicals is ultimately harmful to the soil, their own health, and the environment generally. They have also found that by employing conservation tillage and crop rotations they can achieve yield levels within about ten percent of conventional farming practices and attain the same level of profitability.

This suggests that an important aspect of the technology use decision mechanism shown in Figure 5 is the quality of the information flows along each of the linkages. Do farmers really get accurate information on technology impacts and productivities and do they accurately perceive long-term negative impacts? The agricultural extension service does not disseminate information on organic agriculture, indeed much of the technical information does not exist according to the recent DOE Science and Education Division report (USDA, 1980b). Since many of the practices involve reducing the level of equipment and chemical usage, information about non-chemical techniques is not disseminated by manufacturers. There is reason to believe, therefore, that some important information flows shown in Figure 5 are biased (Just, et al, 1979).

Data is needed therefore on the technical coefficients linking the long-term use of combinations of no-till and rotation (and other) practices to both yield and soil productivity. At the same time, efforts should be made to increase the accuracy of the perception of the causal linkage between technology use and soil productivity on the part of the farmer. If perfect information existed on all technologies and their impact on soil productivity, Figure 5 would indicate that, in the present environment of rising output prices, more technologies would be used but that increased costs of energy-intensive technologies would mean a shift from these to conservation technologies. The more the linkage between technology and soil productivity is correctly perceived, the greater will be this shift. This is beginning to happen in U.S. agriculture today.

Data relating the effect of a technology on yield alone is decidedly not sufficient to determine its long-term impact on the physical, chemical and biological elements of the soil productivity system. A given technology may have an immediate positive effect on current yield, but may inhibit physical processes that contribute to long-term productivity such as the effect of fertilizer use on soil acidity. The use of one technology may preclude or require the use of another.

The most salient argument for suspecting that marginal product determinations are not true measures of technological impact is that such estimates are made based upon "total factor yield" tests in which several factors are varied simultaneously and systematically so that the effect of any one factor on yields can be statistically separated. But the results from such tests are indeed the net effects of factor A on yields. As shown in Figure 5, technology A will have a positive direct effect on yield but may impact yield negatively through either its short- or long-term effect on soil productivity. The use of heavy eight-row farm equipment is an example of a new technology leading to increased farm profitability. While the immediate effect is to produce a harvest at lower capital costs in any one year, the shift away from contour cropping and terracing required by the larger equipment results in definitely increased levels of erosion and hence loss of productivity after a number of years, the time being dependent on local weather.

It was observed in Section 1.3 that differences between social and private time horizons are a prime reason public collective goods are not managed in the socially optimal manner by private individuals. Public policies may have to be designed to achieve a more socially optimum behavior by resource proprietors by facilitating the perception of technology impacts on productivity through scientific experiments and information dissemination. Woodruff (1980) discusses perception and information problems in the context of wind erosion technologies. The second difficulty with the decision system as shown in Figure 5 is that it does not show:

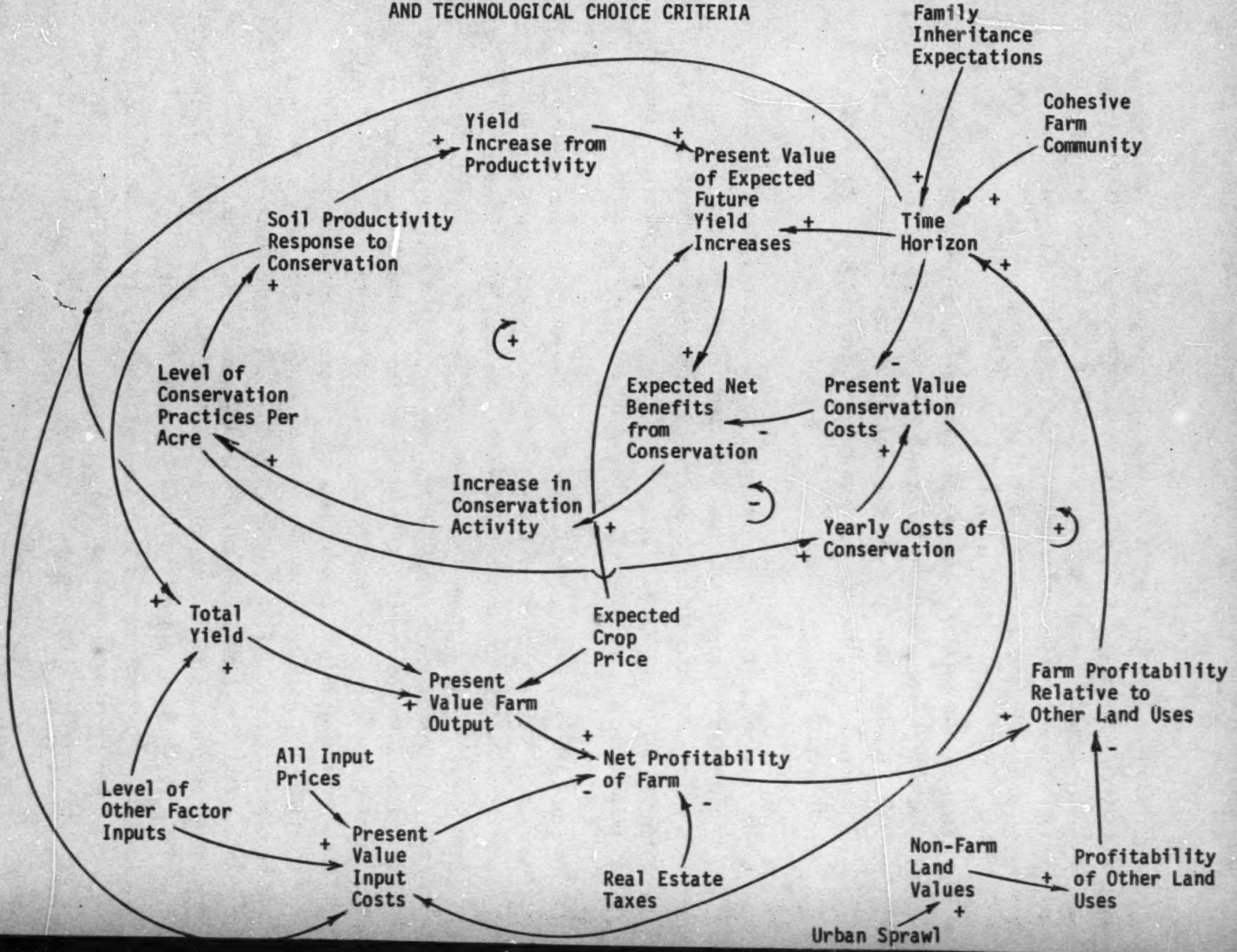
- the manner in which farm operator time horizon enters into the technological choice decision calculus; and
- the manner in which long-term chronic decreases in soil productivity impact the long-term decision calculus which determines the choice of technologies.

A farm operator will choose technologies so that the net benefits to his farm operation are maximized when discounted over his planning time horizon. This is done with the aid of forecasted crop prices and costs of farm equipment and other inputs. Figure 6 shows the causal linkages between individual farmer time horizon and technological choice criteria.

Consider the case of a conservation technology such as windbreaks or terracing. For any given level of this technology, there is a soil productivity response and an increment in the current yield that would not have occurred had the technology not been implemented. This yield increase results in a positive present value of revenue (output times expected price) discounted over the farmers' time horizon. The level of conservation practice also involves a cost, which is also discounted to present value. A comparison of the discounted costs and revenues yields the expected net benefits which, if great enough lead to a maintenance or even an increase in conservation activity. The feedback loop just described is positive, which means that a change in any one of its elements is reinforced by the action of the loop so that the element tends to continue to change in the same direction. It can be seen that if at any time the expected costs exceed the expected benefits then conservation activity will be reduced, soil productivity will decline, the present value of yields will decline and soil conservation activity will be reduced further.

Figure 6

THE INTERACTION OF TIME HORIZON, SOIL PRODUCTIVITY AND TECHNOLOGICAL CHOICE CRITERIA


Family Inheritance Expectations
Cohesive Farm Community
Time Horizon
Yield Increase from Productivity
Present Value of Expected Future Yield Increases
Soil Productivity Response to Conservation
Level of Conservation Practices Per Acre
Expected Net Benefits from Conservation
Present Value Conservation Costs
Increase in Conservation Activity
Yearly Costs of Conservation
Total Yield
Expected Crop Price
Present Value Farm Output
Farm Profitability Relative to Other Land Uses
Net Profitability of Farm
All Input Prices
Level of Other Factor Inputs
Present Value Input Costs
Real Estate Taxes
Non-Farm Land Values
Profitability of Other Land Uses
Urban Sprawl
+
-

The critical question of whether discounted benefits exceed costs of a given techology depends on the relative time streams of perceived benefits and costs and the time horizon. For conservation practices such as hedgerows or terracing with a high initial investment followed by maintenance costs, a short time horizon would tend to accent the costs relative to the income stream from increased crop production. The longer the time horizon, the greater is the chance that the benefit stream will dominate the initial investment costs, especially if future crop prices can be expected to rise relative to present input costs. Figure 6 shows that factors which tend to reduce the farmers' time horizon may have the effect of reducing the benefit/cost ratio of technologies and management practices which have long-term payoffs, and thus result in reduced application of these technologies.
decrease due to competing land uses from urban sprawl, even if individual
Also shown in Figure 6 is a feedback loop linking the level of conservation activity to total yield, net farm profitability (after all factor costs have been considered), and eventually the profitability of the farm operation relative to other land uses. Reduction in conservation activities affects total profitability through this loop. Relative farm profitability can also

farms are still profitable. This, along with the erosion of a cohesive farm community and the lack of heirs intersted in preserving farming as a way of life are some of the economic and social reasons why time horizon itself can decline.

The two feedback loops of Figure 6 can now be used to explain the syndrome of the eroding farm which is abandoned because it is too costly to maintain in a productive state, or the evolution of still productive farmland to suburban or exurban uses due to competing land values and the erosion of the farm community.

In summary, the fundamental point illustrated by Figure 6 is that time horison is causally linked to conservation technologies and soil productivity through positive feedback loops so that the more soil productivity declines, the lesser are the chances that social and economic pressures will cause the individual farm operator to come to the rescue. Furthermore, technological impacts on soil productivity, which may be masked, underestimated, or ignored by a concentration on total factor yields may be a factor in initiating social and economic forces that hasten the decline of individual farms. The feedback loops shown in this section have illustrated that soil productivity plays an important role in the choice of agricultural technologies by farmers. Also illustrated is that the application of technologies is controlled by both short-term economic considerations and long-term social and economic concerns interacting with such factors as prices and land values over which the individual farmer has no control.

2.6 SOME CHARACTERISTICS OF AN AGRICULTURAL TECHNOLOGY POLICY MODEL AND DATA BASE

Beginning with a discussion of the important physical, biological, and chemical processes which determine soil productivity, the manner in which generic technologies impact the "natural" system was characterized. The issue of what determines the use rate of these technologies was raised with the finding that there are important social and economic forces acting on the individual farm operator which may cause him to choose technologies which do not necessarily result in the long-term preservation of soil productivity. The fundamental points illustrated by the feedback loops in Figures 5 and 6 are that soil productivity per se is not coupled in any strong way to the choice of a particular technology and that such choices are not necessarily in the best long-term interests of the society at large.

The purpose of the discussion so far has been to define the system surrounding soil productivity and agricultural technologies. This description will indicate some of the characteristics of a policy analysis model and from this the data requirements for assessing agricultural technologies can be derived.

A useful model which can be used to assess the impact of agricultural technologies on soil productivity must include the following concepts:

- Representation of the Natural System. The major physical, chemical and biological processes must be represented and connected by the major causal linkages that are known to exist and which transmit impacts throughout the natural system. It is not sufficient to represent erosion rates only. The mechanisms for both increasing and decreasing productivity must be included in the model so that it is possible to find the sustained yield level of any technology mix. This is almost analogous to saying that the rate of soil formation should be simulated so that individual tolerance levels (T-values) can be calculated. Productivity is a slightly more comprehensive concept than soil formation, however, since it involves the capacity to perform the biochemical services necessary for nutrient mineralization and plant growth.
- Explicit Linkage of Technologies to Natural System Elements. At whatever level of detail a policy study is made, the impact point of each technology must be identified as to the direction and magnitude of the causal effect.
- The Microeconomics of Technology Choice. The microeconomics of individual operator technology choice which determine the magnitude of use and the economic conditions under which the technology may tend to proliferate, must be included. The existence of perfect unbiased information available to farmers should not be assumed. It may be necessary to include such biases in the model structure explicitly.
- The long-Term Impacts on Total Farm Profitability. The long-term feedbacks from use of a technology, how the farmer perceives these impacts, and how these affect farm profitability over the long-term, must be included.
- The Interaction of the Technology and Changing Social Values Changes in a farmer's time horizon, how these affect technology choice and the linkage between time horizon and social and economic trends must be included. This is important to capture the extent of cropland as well as the quality of land, since land movement in and out of service is not a reversible process.

Beyond the conceptual attributes above, some additional specifications of a policy decision model are evident:

- The time horizon of the model must be on the order of a generation to register significant trends in soil productivity and the consequences of long-term social and economic feedbacks.
- Any formal model must employ a methodology that explicitly portrays the important feedback dynamics occurring throughout the system.
- Due to the structural complexity required by the comprehensive nature of the policy model in this area, a useful, understandable model must necessarily be aggregate, testing generic types of technologies and policies. Although it will be useful to examine national policies, it will probably be necessary to examine policies at the regional level, for example, for the purpose of implementation. The high degree of variation even within regions means that "representative" data sets will have to be constructed, since aggregate models with weighted averages for parameter values may not be internally consistent.

There are two kinds of data necessary for parameterizing such a policy model. The first is descriptive data about the time histories of the important variables along with the levels of the exogenous variables. for example the changes in organic matter over time and the levels of technologies applied. In order to validate the policy model, descriptive data must be available for some period of time for which both the technologies and state variables have changed. The other type of data is causal information about how each element of the system affects each other element. Although time series data is not necessary about these, information is necessary for the whole range of each parameter. The parameters and relationships for which data must be found have been described in general terms in Figures 2 through 6 above and in the accompanying text. A more precise definition of data requirements must await a more detailed model framework, which is only possible after one decides on the policies to test.

3. DATA AVAILABILITY

3.1 DESCRIPTION OF AVAILABLE DATA SETS

There is no existing electronically readable data set containing data on soil productivity. What follows is a discussion of some of the data sets that seem most relevant and the extent to which they may contain useful data on the system elements discussed in Section 2.

There have been countless crop yield experiments performed and reported in the agricultural literature for the last several generations. Few of these experiments were conducted in a manner that would allow the determination of intrinsic productivity, however. Furthermore, the sites upon which the experiments were done were not selected in a manner that would allow scale up of the results, nor are the data computerized so they may be readily used in policy models. It makes sense, therefore, to limit the discussion here to electronically readable data sets, having national coverage, containing data collected in a consistent fashion or selected according to a consistent set of criteria and having some information of use for the assessment of technological impacts on soil productivity.

Table 4 shows some of the data sets which meet the above criteria. Table 4 should be considered to be a fairly representative sample, but not a complete list. While there may be other data sets in existence containing useful data, for example on specific technologies, specific crops, national weather data or regional water inventories, it is fairly certain that there are none significantly better suited for technology assessment of productivity than those already listed in Table 4. The "public" column indicates whether the data base is available to non-governmental entities. The FIPS code is the Federal Information Processing Standard code, which allows one to label data base entries in a consistent manner among all the government agencies. Having a FIPS code means data collected from diverse sampling units can be aggregated, disaggregated and compared. The "data" column is meant to represent the type of data, not to be a catalog of everything in the data set.

Table 4

CHARACTERISTICS OF VARIOUS AGRICULTURAL DATA SETS RELATED TO SOIL PRODUCTIVITY

Dataset	Date	Author	Location	Electronic	Public	FIPS Code	Policy Models	Aggregation	Data
1. Conservation Needs Inventory, CNI	1967	Soil Conservation Service, SCS	D.C.	Yes	?	Yes	None	County	Land class, present use, slope, management factor, irrigation,
2. Potential Cropland Study	1977	SCS	D.C.	Yes	Yes	Yes	NALS, National Agri. Lands Study	PSU	Potential arable cropland, present use, potential for reconversion to cropland, Universal Soil Loss Equation parameters, soil and water problems
3. National Resources Inventory, NRI	1977, 1982	SCS	D.C.	Yes	?	Yes	NALS, RCA, Iowa LP	Major land resource area, MLRA	R-factor, slope, length, present use, soil class, conservation practice, treatment needs, potential cropland, erodability, type irrigation, ownership, crop management, dominant problems, assoc. water bodies.
4. Crop Consumptive Irrigation Requirements	1976	Soil Conservation Service, SCS	D.C.	Yes	Yes, public access via extension	No	Used in ISU-LP	Crop specific in each county	Irrigation requirements net of rainfall for each crop in each county.
5. Agricultural Census, OBERS	1974, 1978, 1982 every four years	Dept. of Commerce, DOC, ESS of DOA	D.C.	Yes	Limited dist. for labor stats., ESS data public	Yes	Inputs to NIRAP model	Water Resource Council Regions, WRC	Farm income, production, value of farm, outputs, factor inputs, land cropped, irrigated land, tenure, employment.
6. National Pedon Data System	ongoing	National Soils Survey Lab, DOA	Lincoln, Nebraska	Yes	Yes	Yes	None specifically	Site-Specific with geographic coordination	Site description, slope, drainage, cultural uses, 7 horizon files, physical and chemical lab tests, minerology data, some engineering data, closest weather station, climate data. Most representative soils in each country being coded first.

Table 4 (Continued)

CHARACTERISITCS OF VARIOUS AGRICULTURAL DATA SETS RELATED TO SOIL PRODUCTIVITY

Dataset	Date	Author	Location	Electronic	Public	FIPS Code	Policy Models	Aggregation	Data
7. Yield/Soil Loss Simulator data, Y/SL	1980	DOA SEA	D.C.	Yes	Yes	Yes	Yield-Soil Loss Simulator Model, SEA	Soil mapping unit, SMU	240,000 observations, variety of crops, texture, slope, class, county, SCS yield, Normalized yields.
8. Crop Reporting Board,	Yearly	Economics & Statistics Service, DOA	D.C.	Yes	Yes	Yes	Yearly crop yield projections	County	Yield data for all major crops, factor inputs.
9. Phenological Model Data	Being developed now	SEA of DOA	Temple, Texas	Yes	Yes	Yes	Input to Iowa State LP model	Crop and soil type specific	Physical, chemical and botanical data relating technologies to yields, hydrology and soil class to erosion and productivity.
10. Soils V	Ongoing	SCS	D.C.	Series - yes Maps - No	Yes	No	Yield/Soil Loss	No geographic Reference	12,000 soil series records, cultural data on use suitability, survey maps show soil types for locations, 65 percent of country classified, yield and performance ratings, cost of restoration.Soil survev information such as slope, texture, capability class, use, erosion phase, irrigation practice.
11. National Woodland Data System, Range Data System	Ongoing	SCS	Fort Collins, Colo.	Yes	?	Not Yet	None yet	Site specific	Growth rates of trees on specific kinds of soil for over 20,000 sites, range data system contains forage production and species composition.
12. Agricultural Research and Inventory Surveys through Areal Remote sensing, AgARISTARS	Ongoing	DOA SEA	Temple Texas	Yes	Yes	Yes	Phenological models	25x25 mile grid	Information on the most representative soil series in each 25-mile square for a National grid, soil survey information, land use, cultivation practice, location of nearest weather station.

The soil surveys performed by the soil conservation service, SCS, contain a wealth of information on soil classes, subclasses and series which give chemical, physical and cultural attributes for 12,000 different soil types. Soil surveys have resulted in the classification of and location of soils for 65 percent (by land area) of the counties in the United States showing, for a given location, what type of soil exists (United States Department of Agriculture, 1979a). Much of the descriptive information on soil classes has been computerized in the "Soils V" data base, which contains the parameters necessary for the universal soil loss equation, although "Soil V" does not include geographic location data (United States Department of Agriculture, 1979b).

Correspondence between geographic area and soil type can be made through the use of two data sets; The Agricultural Research and Inventory Surveys through Areal Remote Sensing, AgARISTARS, and the National Pedon Data System. AgARISTARS contains data on the most representative soil type in 25-mile squares for a national grid, whereas the National Pedon Data System is a data base of all the soils that pass through the National Soils Survey Lab in Lincoln, Nebraska. Although the Pedon data set contains the exact geographic coordinates for each soil sample, efforts are being made to choose the most representative soil in each county. While the Soils V data bank contains more conceptual data on the ranges of soil characteristics in each class, AgARISTARS and the Pedon data sets endeavor to progressively narrow the range by focusing on specific locations. These data sets are perceived as general resource bases for research purposes, when they are completed.

There have been a series of land inventory surveys which include the "Conservation Needs Inventory" (prior to 1970), potential croplands interim study in 1977, (United States Department of Agriculture, 1977) and the "National Resource Inventory", which began in 1977 and will continue periodically (United States Department of Agriculture, 1980a).

The purpose of these surveys has been to inventory the land area of the United States by sample surveys which now collect data on the present land use, crops, irrigation, soil type, potential for reconversion to cropland from nonagricultural uses and a range of data on erosion status and needed conservation practices. The tendency of the inventories has been to become more intensive, covering a wider range of land-related concerns, and less extensive, employing a smaller sample fraction. The consequence of the smaller sample fraction is to render the results accurate at a more aggregate level (Major Land Resource Area, MLRA instead of county). The data is collected from primary sample units, PSU's, of 160 acres each by a Soil Conservation Service technician who actually visits the site and observes the land use conditions as well as taking soil samples from three points within the PSU.

Altogether the soil surveys and the national inventories contain data in the following general areas identified in Section 2 as necessary for a technology assessment:

- soil type, especially organic matter content and nutrients available;
- yields, and crop patterns that would allow weighted average yields;
- erosion rates and the parameters necessary for calculating the universal soil loss equation;
- present technology inputs in the area of conservation practices, irrigation practices (but not actual water application rates), windbreaks;
- land conversion rates and the data necessary to qualitatively estimate some of the social and economic forces which may cause time horizons to change and the profitability of farming to become unattractive relative to other uses (there is a less complete set of data in this area collected for NRIs before 1980);
- information about erosion problems, ownership, type of restorative treatment needed and irrigation practices;
- indices that allow the aggregation of the data according to various land area schemes MLRA, WRR, PA, SMU, County, State, etc.

County-specific data on a range of yield and economic parameters are collected and computerized on a yearly basis by the Crop Reporting Board at the Economics and Statistics Service, ESS, of the Department of Agriculture and periodically by the Department of Commerce via the Agricultural Census. The types of data available from these sources would be useful for a technology assessment are:

- yields, prices and the values of all factor inputs in the agriculture sector so that marginal value products can be derived;
- the ESS forecasts of expected prices and factor costs so that estimates of expected profitability can be made.

The Soil Conservation Service maintains a data base on crop consumptive water needs which, in conjunction with climatological data, (available from the National Oceanic and Atmospheric Administration, NOAA, and not reviewed here) can be used to estimate irrigation requirements. There is no information in this file on actual water consumed, nor is there a uniform system of gathering information on irrigation water application rates that is compiled nationally, although a few states are reported to collect this information (Lehr, 1980). Useful data from this source are:

- estimates of irrigation needs which could be used as one of the determinants of groundwater extraction rate.

Data developed for the purpose of estimating coefficients for the yield-soil-loss-simulator (to be discussed in Section 4) has been stored as an independent data set. Although data on erosion rates, management practices and yields are included in this data set, it does not seem that these data will be wholly sufficient for a causally-structured model. This is because a causal model, as shown in Figure 2, specifies that erosion rates result from changes in physical properties as well as management practices. Since the yield-soil-loss data set is made up of information from five other data sets, there is no unique data here that cannot be found in sources previously mentioned (Hagen, 1980).

The national woodlands data system (McCormack and Decker, 1980) includes data on the production or yield response to soil type for a wide range of forest and forage species. This type of data may be of use to parameterize the yield equation in a technology assessment model.

The National Water Data Exchange network is a group of over 400 contributors of data on all aspects of ground and surface water quantity and quality. NAWDEX is an index only with which it is possible to identify appropriate water-related data sets (Edwards, 1981).

Finally, as a result of building a set of crop-specific phenological simulation models (to be described in Section 4) the Scientific and Educational Administration (SEA) of the Depratment of Agriculture is presently constructing a data base which includes, for each major soil class and crop rotation, modules to simulate crop growth, soil runoff, soil texture, organic matter, nutrient levels, water infiltration and residue decomposition. This data set will thus be the only computerized file that relates yields to soil productivity and productivity to the physical, chemical and biological processes at work. Data of use for technology assessment will be:

- the physical, biological or chemical impacts of a specific technology on the natural system;
- the causal mechanisms underlying erosion, organic matter accumulation and decomposition;
- the dynamics of the nitrogen and phosphorus nutrient cycles;
- the linkage between the natural system and runoff, which is necessary in estimating pollution loads in streams and groundwater recharge.

3.2 CONSEQUENCES OF MISSING DATA AND CONCLUSIONS

In summary, there exist a number of accessible electronic data sets which are national in scope and capable of being cross-referenced. The data on any one file, however, is not sufficient for the assessment of agricultural technologies on productivity. The following conclusions about data availability are based upon the conceptual model discussed in Section 2. Of course, it will be possible to make more specific statements about data availability once a model is actually formulated to address some subset of all the possible policy questions.

Among the more useful data sets are:

- the National Resource Inventory, especially in its current augmented form; for land use and class, data and information on conservation needs and land evaluation;
- the ESS and DOC census data on agricultural economic parameters;
- the data on natural system interactions being developed by the SEA "wheat yield group."
- the soil classification and capability data sets compiled by the Soil Conservation Service.

These data sets provide qualitative or quantitative information necessary for a large part of the system structures discussed in Section 2, mainly:

- long-term land use change rates;
- the levels of factor input use;
- some of the natural system linkages which affect the determinants of productivity such as erosion, and the level of organic matter.

This data is largely descriptive, relating to the state of the parameter. In some cases it may be possible to construct time series estimates, in the case of the levels of factor inputs and yield from information reported by the ESS Crop Reporting Board. Erosion time series and other information from the various land inventories can be merged although this would probably not be a simple task.

Data sets are lacking, however, in a number of important areas that were discussed in Section 2. These are:

- Data on the impact of technologies directly on soil fauna and flora of a micro-and macrobiological nature. These biological organisms provide important services since they are linked to the rates of decomposition, tilth formation, and nitrogen fixation.
- Although some data exists on water requirements, there is no data on water withdrawals from aquifers. Likewise, data exists on pollution constituents in water bodies, but the causal linkages between chemical application and recharge pollution have yet to be developed and organized in a way useful for policy analysis.
- Data in needed on the socioeconomic determinants of groundwater irrigation and likewise the causal linkages which cause a reversion to dry-land farming or abandonment when faced with the combined facts of water costs, pollution, subsidence, and salination.
- Although some information is being developed by the NALS study and the NRI surveys on land evolution, there does not exist data on the linkages between farm profitability and time horizon, how these and other social factors combine to change factor inputs and whether these changed inputs will be the kind which will accelerate or decrease profitability declines.
- Data is needed on the extent to which farmers correctly perceive long-term productivity impacts of technology use (where such impacts are known).
- Data is needed on the extent to which short-term factor input decisions result from social, ecological, health and other "non-economic" concerns.
- A data set does not exist on intrinsic productivity by area in the United States, nor is there information about the role of intrinsic productivity in total factor yields.
- Data is needed on the linkages between the natural system and the groundwater system. Although some of the individual linkages may be quantified, such as the effect of water as an input to yields, information on the effects of deteriorating water quality on yields directly, or on productivity or microbiological activity, for example,

does not exist. Also, the local hydrogeological cycles are only now being modeled in sufficient detail to permit assessments of the system-wide effects of recharge pollution and aquifer drawdown (Vanlier, 1980; Lehr, 1980).

In summary, some data exists of a descriptive nature on the important paameters for a productivity policy model. There is almost a total lack of organized data on the causal linkages, however, which define how changes in one parameter effect another. In the area of physical-chemical soil relationships, some of this causal data exists in the literature for specific soils in specific regions and needs to be standardized and organized, if this is possible. Some of this is being done by the wheat yield group at Temple, Texas for the phenological models. As far as actual productivity, T-values, and rates of soil formation are concerned, however, the necessary scientific experiments have not been done. In the area of economic decision-making, there is almost a total lack of data on how farmers perceive productivity and what this means for their decision-making. Attitude studies of organic farmers and technology transfer indicate the importance of farmer perceptions and the possible bias in information available to all farmers. In the area of long-term decision-making, there is again a lack of information on the role of productivity in the evolution of land from productive cropland to other uses, even though the changes in cultivated acreage can be fairly well described through time. One can say with some degree of accuracy that we know, in a qualitative sense, what has been happening and this has been reviewed in the recent National Agricultural Lands Study (National Association of Conservation Districts, 1980). We do not know the quantitative extent to which productivity has been declining, however. While we do know that productivity declies have alot to do with erosion exceeding T-values, we cannot say with assurance exactly what are the attitudes, economics, values, technologies and public policies that result in productivity declines. The causal data are simply lacking.

The consequences of msising data in the above areas are that only incomplete models can be used to test agricultural technologies. This is a problem when the missing system structure causes one to ignore an important causal linkage that may severely limit productivity in the future. Using the system structure in Section 2 as a framework, some of the consequences of the missing data noted above may be:

- Soil fauna and flora could be impacted in terms of total numbers or species composition so that essential services are lost, such as the mediation of biogeochemical cycles or soil formation. Excess "pollution" will be generated.
- Rational means of allocating scarce groundwater resources cannot be developed until use rates can be discovered and enforced. Social control of groundwater pollution cannot proceed until aggregate data bases are assembled on the physical impacts of chemical applications.
- The loss of agricultural land is part of a feedback process involving productivity. Unless we can manage to learn about the long-term social and economic forces that determine input factor use, the positive feedback loop linking land deterioration with land management may result in socially "wasted" croplands or extremely naive laws to control the process.
- The absence of data on intrinsic productivity and the consequent ignorance of how this affects yields, may lead farmers to make woefully inefficient choices about factor inputs. This results in economic waste and also non-optimal resource use, from a social point of view, since the soil resources may be degraded and jeopardize agricultural production.
- The absence of data on soil tolerance limits (T-values) means that, even with all the data presently available on soil characteristics and erosion rates, it is impossible to tell whether a particular set of technologies or management practices is a sustained yield policy. Since loss of organic matter through excess erosion

is probably the single most important factor contributing to productivity declines, the establishment of a data base on soil formation rates under various climate and management regimes is the most important single generic type of data needed to assess agricultural policies.

All of these consequences of missing data relate to the important social issues for concern outlined in Section 1. The issues of land tenure and water rights (resource ownership), the issue of time horizon differences and the socially optimum management practices, the issue of pollution externalities and finally the issue of irreversible damages are all implicit consequences of these missing data. Table 5 summarizes some of the above points.

Table 5

MISSING DATA IMPACT MATRIX

Missing Data On	Pollution Externalities	Socially Non-Optimal Use of Resources	Irreversible Changes
1. Technology -- Soil fauna and flora impacts.	Impairment of biogeochemical cycles.		Damage to biogeochemical cycles.
2. Groundwater use, pollution impacts.	Groundwater pollution.	Aquifer depletion.	Fossil aquifer contamination.
3. Linkages between natural system and groundwater.	Groundwater pollution.	Aquifer depletion.	Land salination, groundwater distruction.
4. Intrinsic productivity and changes.		Sub-optimal factor inputs to agriculture.	Loss of soil resource.
5. Determinants of long-term land evolution.	Loss of Landscape diversity.	Sub-optimal public policies about land use.	Loss of prime cropland.
6. Non-economic factor input decisions.		Public policies inadequate -- ignoring socioeconomic forces.	
7. Rate of soil formation, erosion "tolerance value".			Loss of soil resource

4. REVIEW OF SOME AGRICULTURAL POLICY MODELS

4.1 PURPOSE

The purpose of this section is to review the extent to which current agricultural policy models include the structures and data necessary to evaluate the impact of agricultural technologies on soil productivity. The simple answer to the question is that no model methodology currently contains an explicit representation of how soil productivity is affected by techology applications, nor does any methodology include as broad a perspective of natural system, short-term microeconomic, and long-term social feedback mechanisms as represented in Figures 2 through 6. The following model descriptions include one model currently under development which does represent the soil productivity dynamics as well as seven other model efforts that run the gamut of policy model methodologies. These will provide some insights into the state of the art policy modeling and the basis of recommendations about future directions. The following descriptions are not presented as an exhaustive survey, since there doubtless exist many other models which are variants of the following methodologies, differing in level of aggregation or policy emphasis. The following descriptions do touch upon the entire range of major techniques now employed by explicit models used in government and research stations to analyze policies and, to a more limited extent, carry on agricultural research.

4.2 DESCRIPTION OF SPECIFIC MODELS

The following discussion will elaborate the summary descriptions of six computerized policy models shown in Table 6. Two additional models are discussed below because they are related to the issues of agricultural pollution and farm economics. The first eight row headings in Table 6 relate to the desirable characteristics of a useful technology policy analysis model described in Section 2.6. The remaining rows note the developers of the model, dates and location.

4.2.1 THE IOWA STATE LINEAR PROGRAM MODEL (ISU-LP)

The Iowa State model is a large scale linear optimization program which minimizes the cost of crop and livestock production subject to constraints on the total production needed and a range of policy-oriented constraints such as crop rotation requirements, water supply constraints, or conservation practices. The model produces factor demands, crop and livestock output, farm income and some environmental parameters for 105 producing areas in the United States, 28 market regions and 8 major zones. The model is not simulated, but solved once for projected levels of demand in future years such as 2000 or 2030.

Chief among the environmental parameters produced by the model is an estimate of the erosion resulting from a given crop rotation, management practice and geographic setting as calculated by the universal soil loss equation. It is this relationship that allows one to test the cost of conservation policies by constraining the tons per acre soil loss. In response to such a constraint, the model will calculate shifts in such things as crop patterns, factor inputs and transportation requirements in case the policy resulted in a regional deficit that had to be supplied from another

Table 6

CHARACTERISTICS OF AGRICULTURAL POLICY MODELS

Model Criteria	Iowa State Linear Program	National Interregional Agri-Projections System, NIRAP Forecasting Simulator	Phenological Models, Feedback Simulation Model	Yield/Loss Simulator, Statistical Regression Model	POLYSIM, Econometric Simulation Model, Marginal Analysis	AGRIMOD, Dynamic Simulation/Optimization Model
NATURAL SYSTEM	No productivity, no natural system dynamics.	No productivity, no natural system dynamics.	Organic matter, hydrology, no soil microbiology.	Erosion directly affects yield. No other linkages.	No natural system dynamics, no impacts on soil productivity.	No natural system effects on intrinsic soil productivity.
TECHNOLOGY LINKAGE	Impacts erosion and yield only.	Technology does not impact natural system.	Explicit to natural system.	Technology impact through unversal soil loss equation.	Factor input prices affect output directly, no factor use rates, no production function.	Technology affects yields directly in production functions.
TECHNOLOGY CHOICE ECONOMICS	Endogenous factor input choices.	No endogenous technology choice.	None.	None.	Output levels respond to relative output prices, and assumed factor input prices.	Endogenous factor input choices based on prices.
LONG-TERM PROFITABILITY IMPACTS	Cultivation based on current year economics only.	No profit structure.	Costs will be output for each rotation, technology choice	None	Short-term farm economics, no feedback to conservation practice.	Farm income used as objective funtion to decide on land allocation and fertilizer and machine inputs.
CHANGING SOCIAL VALUES	No time horizon or endogenous social changes.	None.	None.	None.	Time horizon not dynamic.	No effect of farm profitability on conservation practice, urbanization pressure endogenous.
TIME HORIZON	1980, 2000, 2030.	1985, 2000.	50 to 100 years based on weather generator.	50 years.	3-5 years.	15-20 years.
FEEDBACKS EXPLICIT	Some feedbacks implicit in model structure.	No.	Explicit feedbacks simulated.	Yield-erosion-yield is only feedback.	Only microeconomic feedbacks included.	Some interactions of input, wholesale, retail markets simulated. No time horizon changes.

Table 6 (Continued)

CHARACTERISTICS OF AGRICULTURAL POLICY MODELS

Model Criteria	Iowa State Linear Program	National Interregional Agri-Projections System, NIRAP Forecasting Simulator	Phenological Models, Feedback Simulation Model	Yield/Loss Simulator, Statistical Regression Model	POLYSIM, Econometric Simulation Model, Marginal Analysis	AGRIMOD, Dynamic Simulation/Optimization Model
LEVEL OF AGGREGATION	105 producing areas, PA.	4 regions in United States.	Crop and soil type specific, larger by use of Benchmark' data	Producing areas, PA, within water resource region, WRR.	4 crops, 7 livestock, national production.	National plus 7 regions.
USE MODE	Policy studies, optimization given policy constraints.	Generates crop demands, land use constraints for Iowa State LP model.	To be used with Iowa State LP model or for individual policy analysis.	Used with ISU-LP, RCA study.	Marginal change in base line due to national economic policies; marginal analysis.	Effects of technology, energy, national policies on food supply.
AUTHOR	E. O. Heady, et. al at Iowa State University.	DOA.	Wheat Yield group, W. Willis, SEA coordinator.	Hagen and Dyke, SCS.	Ray and Richardson. Oklahoma State University.	Levis, et. al, Systems Control Inc.
DATE	Ongoing update and studies.	1975.	Currently being developed.	1980.	1972-Present	1974-1977. (no longer in use)
LOCATION	Iowa State University.	D.C.	Temple, Texas.	D.C.	Oklahoma State University, USDA.	Palo Alto, Calif.

region. Although technologies and cropping patterns result in various levels of erosion, it was not until recently that the addition of the yield soil loss simulator Y/SL (explained below) to the ISU-LP model allowed erosion impacts to be reflected in yield reductions. The ISU-LP model contains no explicit representation of the natural soil system dynamics nor the impacts of technologies on the components of intrinsic productivity. Even so, the feedback loop just described which links technology to erosion, and erosion to yield, which in turn affects factor choice, is the most complete representation of technological impact of any of the models. Ultimately, however, the utility of this approach for soil productivity analysis rests upon the accuracy of the erosion-yield relationship specified by the yield/soil loss simulator model, which is somewhat questionable, as explained below.

Because of the one-time solution method, the model does not include expected prices as a basis for factor input decisions nor is there a provision for factoring in social feedbacks through time horizon changes so that discrepancies between private and social optima can be investigated. Currently, such differences are specified exogenously through the constraints.

The ISU-LP model has been used for a wide range of policy studies from water resource studies to the impact of economic, environmental and resource legislation, and continues to be developed.

The ISU-LP model has recently been used, along with the yield/soil loss simulator to evaluate conservation programs for the 1980 Resource Conservation Act Report (United States Department of Agriculture, 1980d; Heady (1980), to investigate the impacts on agricultural production of implementing specific sets of erosion control practices (Nicol, et al, 1974), to investigate the effects on food production costs of constraining soil loss from agricultural land (Saygideger, 1977), to evaluate the impacts on agricultural exports and food production patterns of controlling non-point sediment pollution in waterways (Campbell and Heady, 1979), to investigate the effects on farm income and commodity exports of various soil conservation regulations (Boggers and Heady, 1980), to evaluate the use of tax policies as a means of implementing erosion control practices (Daines and Heady, 1980), to evaluate the long-term (year 2000) effect of phased erosion reduction through rotations and technology restrictions (English and Heady, 1980), and finally to evaluate the costs of reducing soil loss on Iowa farmland under a variety of tax and incentive programs (Walker and Thomas, 1980).

Although the running costs of the model are less than the original runs which cost in the thousands of dollars, it still costs hundreds of dollars to obtain a solution with the model, and some sophisticated backup in terms of expertise in mathematical programming theory and techniques and knowledge of the relevant software. The complexity of the model, the methdology, and the need for large and accurate data sets to run such optimization models has generally limited the use of the ISU-LP and prevented its installation outside of the University.

4.2.2 THE NATIONAL INTERREGIONAL AGRICULTURAL PROJECTION SYSTEM, NIRAP

The NIRAP system is a set of simulation forecasting models which were developed for the purpose of organizing all the various land needs and projected uses of many federal agencies. Where two or more uses conflict for the same land, the model employs an allocation mechanism to break the tie. NIRAP contains no economic criteria for such allocations, nor does it base projected agricultural demands upon expected prices and other feedback effects. The regional and national demand estimates as well as regional water availabilities have been used as the "right hand side," or the production constraints in the ISU-LP model. Data for NIRAP is collected principally from OBERS (Bureau of Economic Analysis, Department of Commerce), the Water Resource Councils (WRC) and the Economics and Statistics Service of the Department of Agriculture.

The NIRAP model thus meets none of the characteristics described in Section 2-6 as being necessary to analyze technology impacts on soil productivity. No natural system is represented and the model takes no account of technology use, farm economics or the impact of productivity on long-term technology choice. NIRAP is useful, however, as a first order mechanism to integrate plans of numerous agencies and to point out resource use conflicts.

4.2.3 THE YIELD/SOIL LOSS SIMULATOR(Y/SL)

The yield/soil loss simulator is a means of forecasting the yield implications of cropping and management practices of soil losses calculated by the universal soil loss equation. The universal soil loss equation is a regression equation used to estimate erosion impacts given physical soil properties. The model was developed in response to the needs of the 1980 Resource Conservation Act Report to Congress which required, among other things that the economic implications of national soil conservation policies be investigated, (United States Department of Agriculture, 1980d). The effort involved the development of a data base with crop-specific records for 1100 counties which has been described in Section 3 (Hagen and Dyke, 1980).

Although the Y/SL model produced results which were consistent with the results of empirical studies, there is sufficient quantitative discrepancy that the approach has been shelved in favor of the dynamic simulation of phenological systems described below (Benbrook, 1980). Note that, although the Y/SL simulator included slope, soil class, management technique and other inputs to the universal soil loss equation, soil productivity and its components in terms of organic matter, nutrients, tilth, nitrogen fixation potential, etc. were not explicitly represented. The utility of this approach for soil productivity analysis is therefore extremely limited, since it is impossible to define the mechanisms through which technologies impact productivity.

4.2.4 WHEAT YIELD GROUP PHENOLOGICAL MODELS

There are severe limitations in analyzing soil productivity responses with techniques such as the Y/SL simulator which contained none of the causal linkages operating in the natural system shown in Figure 2. Realizing this, the SEA Wheat Yield Group undertook to construct a series of phenological models that simulate the dynamics of plant (crop) growth and how this is affected by physical and biological processes (Dyke, 1980). The crop models will contain at least six modules concerning soil runoff, soil texture, organic matter, nutrient cycles, infiltration, and residue decomposition. There is no macro or microbiological sector as yet. Agricultural technologies will be causally linked to the specific process that they impact, instead of being merely associated with a yield. The models will be crop and soil type specific and have a 50 to 100 year time horizon so that long-term productivity changes can be simulated.

These phenological models are at the focal point of some empirical research and an intensive search through the literature to develop the causal relationships described in Section 3. At least two of these models, for sorghum and wheat, are presently operational.

This phenological model approach is the only methodology of the eight which has promise of being able to capture the feedback dynamics of the natural system including nutrient cycles and organic matter dynamics. Since these models are intended to be linked to the ISU-LP model, there is no effort to develop any of the economic feedbacks or allocation mechanisms through which the use of technology is determined. If successfully merged with the ISU-LP model, these crop phenological models will provide an important feedback missing from the present ISU-LP structure.

A drawback of the phenological model approach is that, even though they only deal with the natural system, they are extremely complex, with over 400 subroutines and only deal with one crop at a specific location at a time. Although the running costs are more reasonable than for the ISU-LP model, about $40 for a set of runs with alternate rotations, the models are presently perceived as research tools more than policy analysis programs. One objective of this effort is to have the phenological models sufficiently complete by 1985 to be useful for drafting the 1985 Resource Conservation Act Report. Between now and 1985, there is no policy analysis model capable of analyzing productivity impacts or of determining soil loss tolerance values.

4.2.5 POLYSIM

POLYSIM was developed at Oklahoma State University in the middle 1970s. It is an econometric simulation model used for marginal analysis of near term (three to five years) economic policies. The model includes four crops, seven livestock sectors and produces aggregate national forecasts. The model works essentially by modifying a prior base line projection in response to a given policy by means of elasticities and cross-elasticities relating the policy to factor inputs and these factor inputs to crop production levels. A detailed overview of the model equations, flow diagrams and history of use is given in the Polysim Bulletin (Ray and Richardson, 1978).

POLYSIM includes no natural system dynamics and no concept of intrinsic productivity. The model has been used primarily to analyze the impact of loan rates, target prices, grain reserve strategies and set-aside payments, as well as exogenous yield per acre increases. A series of twenty-one POLYSIM studies have been published between 1974 and 1977. The model includes the details of net farm income calculations but does not include feedbacks from farm profitability to conservation practices. As such, the model is of little use to estimate the impacts of technology on soil productivity but does provide useful short-term forecasts of the economic effects of a wide range of government price support and subsidy programs.

While POLYSIM continues to be developed at the University of Oklahoma at Stillwater, there is a version that is presently being used at the Department of Agriculture in Washington. The model relies totally on data from the Economics and Statistics Service and, in a deterministic mode, will produce results for under ten dollars per run. A stochastic capability has just been added which increases the running costs by about a factor of ten, however. The model enjoys a level of acceptance and use at the Department of Agriculture beyond that of many other models developed outside because the model structure is extremely easy to understand and the model was developed with the assistance of Department of Agriculture personnel. The model is also used to investigate alcohol production impacts on grain prices for non-Department of Agriculture clients.

4.2.6 AGRIMOD

AGRIMOD is a dynamic simulation model developed in the mid 1970s at Systems Control Inc., in Palo Alto, California (Levis et al, 1977). The model has a time horizon of 15 to 20 years and provides results relative to seven regions in the United States. AGRIMOD simulates the dynamics of farm operator decisions about factor inputs by an optimization routine that maximizes net farm income given factor prices, output prices and a set of production functions relating level of input to farm outputs of ten crops and five livestock commodities. Two other optimizing routines serve to clear the market at the wholesale and retail levels, passing prices back to the primary production sector. The development of AGRIMOD was sponsored by the National Science Foundation to investigate the national impact of agricultural policies.

Although AGRIMOD is the richest of the six models in terms of feedback structure, it too contains no mechanisms to translate technology uses into their soil productivity implications. Furthermore the range of technology choices is somewhat limited, consisting of an aggregate fertilizer level and a level of machinery utilization. The model is the only methodology of the eight that includes an explicit accounting of land area lost to urbanization, although there is no structure that simulates the interaction of land maintenance and the linkages to farm productivity and land values.

AGRIMOD was designed to simulate the effects of technology, energy and farm economic policies on national food supply and agricultural prices and has been used to test, among other things, the effect of energy prices on food production. The model cost about twenty dollars to run, but has been abandoned by NSF and has not been used since 1978. Compared to the other national models, AGRIMOD is just as unwieldy.

4.2.7 AGNET

AGNET is a collection of over 200 farm planning and analysis programs and associated data sets which is supported by six land grant universities. The system is centered at the University of Nebraska at Lincoln but is used by extension services and individual operators in 34 states. By accessing the system, one can find out, for example, the expected costs of producing particular crops in one's area, as well as the expected revenue. It is possible to perform all the calculations needed to determine marginal productivities and arrive at an optimal crop mix and factor input mix as was discussed in Section 2.5. The system includes data bases on machine costs, weather forecasts and market forecasts while the operator supplies his own soil analysis information.

AGNET is not a long-term planning program and does not include productivity impacts. Nor does it calculate social impacts such as agricultural runnoff. Although not useful for long-term aggregate national policy planning, AGNET has disseminated a wealth of information to the individual farmer in an English-language format. Such a system will be an invaluable way of increasing the perception of productivity impacts among farmers, if this becomes a matter of public policy.

4.2.8 CREAMS

The Chemicals, Runoff and Erosion from Agriculatural Management Systems (CREAMS) model is a hydrological model developed to evaluate non-point source pollution (Knisel, 1980). The model contains a hydrologic, chemical and an erosion sector. The hydrologic sector synthesizes rainstorm parameters from climate records and computes the soil-runoff water balance. The chemical sector computes the nitrogen, phosphorus and pesticide balance, degradation, and runoff concentrations. The erosion sector computes erosion and sediment transport for single management systems of complex geometry and slopes.

The CREAMS model is being used by the Soil Conservation Service personnel in an effort to determine generic sets of best management practices for non-point source pollution control. The Environmental Protection Agency is also using the model. Data for the model is obtained from soil maps, the Soils V data set as well as site-specific climate and cultural data. Although the model does not presently include a groundwater leaching component, the model could be used to investigate the impacts of agricultural practices on surface waters. As it stands, the model is too complex for individual farmers to apply, even though it is oriented toward single-field management practices.

4.3 SUMMARY OF THE STATE OF THE ART

At present, the only model methodology that includes specific causal linkages between agricultural technologies and the elements of intrinsic soil productivity is the set of crop-specific phenological models being developed by the Wheat Yield Group. To be useful, this model must be integrated with a structure which models the farmer's allocative decisions and which also accounts for the long-term interactions between land maintenance and macro-socioeconomic forces. Either a model such as AGRIMOD or the ISU-LP model could adequately model the short-term choice of factor inputs. Neither of them includes long-term socioeconomic feedbacks.

In practical terms the greater level of aggregation of AGRIMOD may render it more suitable for such an integration, since the level of detail and consequent running expense and difficulty of the ISU-LP model limit its accessability. Whereas it might be useful to have accurate quantified impacts which are region-specific as a final step in a technology assessment, most of the time a model capable of qualitative or comparative results would be sufficient.

Both the ISU-LP and AGRIMOD models suffer from the fact that they are optimizing models which deal with current information only. In Section 2 above, the role of expected farm profitability was seen to play an important part in technology choice. To the extent that farm decisions with important impacts on productivity are based upon expectations, no methodology so far is adequate.

Note should be taken that, as the richness and complexity of the model increases, the level of detail must decrease in order to maintain some tractability and facility with model operation and data base acquisition and maintenance. None of the models were designed to deal specifically with all of the complex dynamics surrounding soil productivity. Also less detail in the ISU-LP optimization model in terms of geographic regions may be usefully traded for additional structure describing macro socio-economic feedbacks.

None of the above models includes any linkages between the soil resource and the groundwater resource bases. To the extent that groundwater quantity and quality affect technology choice, this is necessary. Although the ISU-LP model includes water constraints and coefficients that generate estimated surface water pollution loads, the model simulates neither the soil degenerative nor the aquifer degenerative dynamics that may result from the application of agricultural chemicals.

It must be emphasized that none of the above models presently has the capability of aiding in the determination of soil tolerance values for erosion control. All of the models are extremely complex, either in terms of their structure, or the shear magnitude of the data they require. Some degree of complexity is certainly mandated by the difficulty of the problems at hand. An emphasis on normative policy analysis rather than scientific research would result in less complex models.

5. CONCLUSIONS AND RECOMMENDATIONS

All of the following conclusions have been remarked on before, however, they will be summarized here for the sake of illustrating the flow of the argument.

- Soil productivity is defined as an intrinsic attribute of the land, differing from total factor yield, which results from the interaction of technological inputs and intrinsic productivity.
- Concerns about soil productivity stem from the collective nature of the resource base. Issues which render soil conservation difficult derive from discrepancies between public and private rights, management time horizons, the presence of pollution externalities and the practical irreversibility of productivity degradation.
- Given the definition of intrinsic soil productivity and the nature of the public issues surrounding soil resource management, causal linkages connecting technology use to soil productivity were defined. The fact that productivity has an important impact on the microeconomics of factor use rates and long-term management decisions leads to the necessity of adding linkages between soil productivity and farm decision mechanisms as well.
- The mechanisms by which a range of generic technologies and management practices impact the natural system were defined. Policies and programs which affect prices were seen to act through the microeconomic system structure on soil productivity. Electronic data bases have not been found that catalog the systemic impacts of a range of technologies although separate studies on single generic technologies do exist in the literature.
- Given the nature of the natural, microeconomic and longer term socioeconomic system linkages, some criteria for a data base as well as a policy analysis model were defined. Both data base and model criteria relate mainly to the necessity of including a broad array

of data and model feedback structures to enable a systematic examination of technology impacts and productivity changes. The technology impact matrix illustrated that technologies affect a diverse array of processes and states within the natural system, and that studying the effects of a technology in isolation, or concentrating on yield alone, is futile from the point of view of long-term understanding.

Attributes of a useful systems model were found to be:

- Inclusion of the internal dynamics and the intersectoral interactions of the natural system, the microeconomic system, the long-term socioeconomic system;
- Explicit identification of technology impacts;
- A time horizon of at least a generation;
- Aggregate in structure and capable of being used for qualitative comparative analysis;
- An examination of the available data bases lead to the finding that no electronic data base exists on the natural system linkages which determine productivity. Furthermore, data is generally lacking on the long-term determinants of conservation practice, the interactions between the soil and groundwater resource base, actual groundwater application rates and aquifer dynamics, the linkages between the natural and microeconomic decision system, and a host of causal linkages within the natural system.
- Any single data base now in existence lacks important sectors. No single data base has all the required information. Merging separate data sets together, although possible given the FIPS code, does not address the issue that these data bases have heretofore concentrated on the extensive description of agriculture, such as acres in a particular crop or descriptions of state variables such as yields and prices, and not on causal linkages between state variables. It is an appropriate characterization to say that the existing electronic data describe a problem but are of little use to analyze ways of dealing with it. It is descriptive and not deterministic.

- The consequences of data base deficiencies follow directly from type of data that is missing, namely that pollution externalities may impose unacceptable social cost, the soil and water resources may be allocated in a socially non-optimal manner. Society runs the risk of irreversible damage to the resource base, or the expropriation of the resource to uses inconsistent with the long-term welfare of the society at large.
- Eight examples of agricultural models were examined for their applicability to the problem of technological impact assessment. No single model met all the criteria of a useful policy model. None of the models include determinations of soil tolerance values, none include interactions between the natural and socioeconomic systems and all were extremely complicated and cumbersome to use.
- Any combination or hybrid of existing model structures remains unsatisfactory because: 1) these models lack biological, groundwater, and long-term socioeconomic sectors; and 2) the separate components of these models are too detailed to render such hybridization a tractible exercise and thus their efficient use would be difficult and the problems of data collection enormous.

Based upon these conclusions which derive directly from the above review of the literature and data bases, some general recommendations are appropriate:

- There is a need for a catalog of data useful for aggregate policy models to increase the knowledge of and use rate of existing information banks.
- A data base is needed on sustained yield values of soil erosion, the T-values, or conversely, the cropping and managment practices that can be supported on each type of soil with no degradation in productivity. Clearly the first task to be performed if one had an adequate policy model and associated data base would be to determine the "sustained yield" level of cropping activities. The sustained yield concept of renewable resource management has been widely and successfully applied to many single species and should be applied to

the problem of sustained productivity of the soil/groundwater system in agriculture.

The presently accepted T-value of 5 tons per acre is probably too high to sustain yields on many farms in the United States. The scientific experiments necessary to construct such a data base on sustained yield T-values under different management practices should be performed. All considered, this is the most important single data requirement.

- A data base is needed on the long-term productivity effects of no-till combined with rotational crop management practices. Information about technology impacts on long-term productivity should be disseminated via the AGNET system to increase farmer's perceptions of the costs and benefits of non-chemical intensive agriculture.
- Beyond sustained yield T-values, a data base is needed on physical soil properties, productivities, sustained yield production and socioeconomic linkages at a level of aggregation appropriate for national policy-making. This should be assembled as a single data set and made accessible for both public and private sector research activities.

An examination of the state of the art of agricultural policy models leads to the following recommendations:

- There is a need for a conceptually broad aggregate model based upon explicit causal linkages to fully examine the long-term impact of technologies on soil productivity. The model should be long-term and constructed as a dynamic simulation. The object of the model should be quick turnaround qualitative comparison of policies affecting technology use and management practices.

- Such models should be developed with the cooperation and assistance of personnel from the Department of Agriculture, but should not be perceived as research models. The models should be capable of organizing and utilizing the wealth of qualitative data that exists to produce aggregate comparative results. It will be years before empirical experiments result in enough reliable quantitative data upon which to base very detailed models capable of accurate forecasts. In the same sense that data on soil tolerance values are the most important information need, policy models to analyze the impact of public policies on the sustained yield capacity, or productivity, of the soil resource base are the most important analytical tool.

- In addition to a policy model oriented toward soil productivity, a model is needed of the generic processes leading to the loss of agricultural land and public policies which may cause land to revert to agriculture. While soil productivity is an "intensive" problem, land loss is an "extensive" problem affecting the absolute quantity of croplands available. At this point it seems likely that both problems can be analyzed with a policy model but both need not be analyzed with the same model.

The following recommendations deal with how systems modeling techniques can aid in policy-making both at the national and local level. These recommendations are based upon the assumption that one or more policy models which meet the above criteria have been developed.

- Formulation of model structures necessary to link technologies to productivity, such as in Section 2, is a useful method of guiding government (USDA) data collection and research efforts. Resources are being committed to the construction of massive data banks. Yet upon examination, one finds that the data is basically descriptive and lacking in the kind of information that would allow assessment of productivity impacts. A more cost-effective way to collect data is to direct the effort according to the policy model needs. The result would be a data bank having less detail on a much broader area including many "causal" relationships.

- To the extent that preservation of the soil resource base is a national objective, all agricultural policies and many land use policies should be evaluated for their impact on soil productivity. The development of analytical model frameworks, such as in Section 2, supported to the extent possible by working models, is the only practical way that such evaluation can be consistently, fairly and rigorously performed. Technology presently exists to construct structure-rich simulation models that are capable of using qualitative data to produce comparative results. This type of model technology has not been employed, however, in the existing set of policy models. The utility of using such a systems approach rests principally in that the model focuses ones attention on system-wide effects instead of permitting one to consider technology impacts on yields alone. In this way, economic and social policies, which are far removed conceptually from the physical system, can be traced back to their impact on soil productivity and the long-term consequences of these policies will be less likely to be forgotten. It would be possible, for example, to require a review of all agriculture legislation so that laws could be made with much greater awareness of the long-term soil resource impacts.

- In order to take full advantage of current capabilities of systems models, some models should be designed to be used for long-term farm planning and made available to farmers via the AGNET system. These models should address the issues of time horizon and the long-term profitability of farming as it relates to sustaining soil productivity. These are the concerns raised by Figures 5 and 6. More sophisticated models can be used by the ESS or SEA to investigate the manner in which real estate taxes, price supports, subsidies, agricultural research, and a host of other factors may impact soil productivity. Thus the activity of attempting to construct a broad-scale systems model may lead to the discovery of public policies working at cross purposes to the objective of sustained yields.

- Some suggestions for specific types of public policies and legislation and some questions that should be examined with such a national soil productivity model are:
  - What is the national impact of increased use of no-till agriculture on total production, farm income and the national economy?
  - What economic barriers presently exist to the adoption of less chemical-intensive agriculture, and what would be the long-term benefits to society of such a structural change in the agriculture sector?
  - What would be the effect on long-term productivity of either eliminating or increasing subsidies for erosion control activities? Are there positive social benefits?
  - What are the implications for landscape diversity, energy use, and the spatial distribution of agricultural production of increased use of crop rotations and mixed farming?
  - What is the impact of a large scale alcohol-from-grain production program on soil productivity?
  - How are farmer's attitudes and perceptions about the utility of soil conservation influenced by price supports, property taxes and the availability and type of information on the consequences of not engaging in conservation?
  - Under what set of economic and social incentives can recently abandoned agricultural land be rehabilitated and brought back into production? Is it beneficial from a long-term economic and social perspective?
  - What effect do price supports have on the use of chemical-intensive agriculture and soil productivity? What effect do fuel price subsidies have?

- Seventeen workshops were convened by the National Agricultural Land Study at various locations in the United States to gather public opinions on how farmers, local officials and members of rural communities view the issues surrounding soil and cropland preservation. The workshops resulted in a diverse array of perceptions about what federal, state and local laws and programs were hindering soil conservation and which ones which beneficial, and local social and community values which farmers feel should guide farm programs.

  This wealth of descriptive information needs to be integrated into the causal frameworks of Figures 2 and 6 to see which of these values, programs and perceived problems impact on soil productivity and how. This exercise will doubtless result in changes to the causal frameworks to make them more detailed. It will also result in a more refined list of priorities for the analysis of public policies than the list above. The type of values and perception information gathered from these workshops is exactly the type of qualitative information which should be integrated by means of a systems model and which is lacking in all of the eight models described above. As explained above, it is these values and perceptions which, together with the economic data, drive the farmer's decision-making.

An effort should be made to seriously address these issues via an interagency task force such as the Office of the Organic Farming Coordinator or the NALS task force. Such an effort should be implemented swiftly and produce some recommendations on federal or local policies rapidly in order to preserve the momentum and enthusiasm of the NALS and Organic Farm Study initiatives. There is a real danger that relegating these tasks to academic research institutions will only result in their becoming invisible with the payoff too far in the future.

In summary, existing policy analysis model technology is capable of aiding in the definition and organization of data useful for furthering the objectives of soil productivity maintenance. At the same time such models can be useful for increasing perceptions of productivity impacts of the individual farmer. Finally, the causal framework which can created is a useful mechanism for the systematic evaluation of public policy to prevent such an evaluation becoming a costly and immense bureaucratic chore. Only through such an examination will it be possible to reverse the slow but costly degradation of soil resources in the United States.

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